Syllabus for a Post Graduate Course in Physics(M.Sc)
St. Xavier's College, Kolkata

1 Introduction

We describe a provisionary syllabus for the Masters Degree in Physics with special emphasis in Astrophysics and Space Sciences in the following sections. In the present section, we outline the modules that make up the the course, while a detailed description of the individual modules appear in the succeeding sections.

1.1 Course Outline

- Core Modules: All six Modules are compulsory.

  1. Mathematical Techniques **C-MTI and C-MTII** 90 Lectures
     150 Marks.
  2. Computational Physics **C-CM** 60 Lectures
     100 Marks.
  3. Classical Physics **C-CL** 120 Lectures
     200 Marks.
  4. Thermal and Statistical Physics **C-TS** 60 Lectures
     100 Marks.
  5. Quantum Physics **C-QMI and C-QMII** 90 Lectures
     150 Marks.
  6. Experimental Physics (Practical) **C-EX** 60 Lectures
     100 Marks.
     Total : 480 Lectures, 800 Marks, 40 Credits.

- Standard Modules: The student can choose any four modules.

  1. Condensed Matter Physics **S-CM** 60 Lectures
     100 Marks.
  2. Atomic and Molecular Physics **S-AM** 60 Lectures
     100 Marks.
  3. Nuclear and Elementary Particle Physics **S-NE** 60 Lectures
     100 Marks.
  4. Plasma Physics **S-PL** 60 Lectures
     100 Marks.
  5. Electronics and Instrumentation **S-EI** 60 Lectures

     100 Marks.
     Total : 240 Lectures, 400 Marks, 20 Credits

- Optional Modules: The student will take up 2 modules consistent with her/his choice of an advanced module (stated later).

  1. Material Science 60 Lectures
     100 Marks.
  2. Advanced Plasma Physics and Non-linear Dynamics 60 Lectures
     100 Marks.
  3. Quantum Field Theory 60 Lectures
     100 Marks.
  4. High Energy Physics 60 Lectures
     100 Marks.
     Total : 120 Lectures, 200 Marks, 10 credits

- Advanced Modules: The student will take up any one of the modules offered.

  1. Astrophysics and cosmology 180 Lectures
     300 Marks.
  2. Space Science and Atmospheric Physics 180 Lectures
     300 Marks.
     Total : 180 Lectures, 300 Marks, 15 credits

- Interactive Modules: All modules are compulsory.

  1. Group / Self Study 30 Lectures
  2. Independent / Directed study in physics 15 Lectures
  3. The methodology of physics / technical literacy 5 Lectures
  4. Colloquium 5 Lectures
  5. Seminar 5 Lectures
  6. Project Work 120 Lectures
     Total : 180 Lectures, 300 Marks, 15 credits

  Course Total : 1200 Lectures, 1000 Marks, 100 credits

2 Module Outlines

2.1 Core Modules

2.1.1 Mathematical Techniques

Analysis-I Notions of Analysis: Sets, Maps, Metric Spaces, Cardinality, Series and Sequences.

Linear Algebra Linear Algebra and Finite dimensional vector spaces.

Analysis-II Infinite dimensional Vector Spaces, Complex Analysis, Differential Equations, Operators on Hilbert Spaces, Green's Functions, Functional analysis and calculus of variations.

Group Theory Symmetries, Representation Theory, Broad overview of finite and continuous groups, Rotation Group, The nature of time-reversal and space inversion operations. Point Groups and crystal tensors : application to X-Ray analysis of structures and molecular vibrations, The Wigner-Eckart theorem. Lie Groups and representations, Young Tableaux, Dynkin Diagrams, Lorentz and Poincare Groups, SU(2), Gauge invariance, SU(3) and Quarks.

Tensors Index Notation, Geometric Invariants and Transformations, Special Tensors, Tensor Derivatives, Differential Geometry.

Spectral Techniques Fourier Theory, DFT and CFT, Convolution, Filtering, Correlation, Applications in Mathematics and Physics.

2.1.2 Computational Physics

This course will introduce the computational methods used to investigate physical Phenomena.

Numerical Techniques : Finite vs. infinite precision calculations, Coding tools: Languages and Libraries, Handbooks, Numeric Differentiation and Integration, Interpolation and Extrapolation Techniques, Special Functions, Matrices : Inversion, LU decomposition, Tridiagonalization, Eigensystem of a tridiagonal matrix; Linear and non-linear least squares, Monte Carlo Calculations, Finite Difference Solution (RK) of Differential equations, Finite Element Solution to PDEs.

Computer Algebra / Visualization Application of copyrighted and open-source non-proprietary software like Mathematica, Matlab, Maple,Gnuplot/Grace etc for performing rapid calculations, prototyping, visualizations and data analysis.

Applications Applications of computational techniques for the study of a variety of scientific problems like Chaos and Nonlinear Dynamics, Initial and Boundary Value Problems, Simulation of Model Systems, Critical Phenomena, Quantum Mechanical Scattering etc.

2.1.3 Classical Physics

Classical Mechanics Dynamical stability, Virial Theorem and its applications, Harmonic oscillator: Introduction to the Phase-Space methods of analysis of dynamical systems, The Nonlinear Oscillator : Approximate methods of analysis -averaging method and series expansions, Case Studies: Van Der Poll's and Duffing's equation. Extended bodies in rotation, Classical Scattering Theory.

Lagrangian and Hamiltonian Mechanics Description and applications of the Canonical formulations of mechanics, Canonical transforms, Hamilton-Jacobi theories, Action angle variables.

Continuum Mechanics Tensor notation for vector quantities, Dynamics, Basic Equations of continuum Mechanics, Solids, Fluids, Electric and Magnetic Fields.

Nonlinear Dynamics Dynamical systems, maps, flows, fixed points and neighborhoods, chaos, fractals and fractal dimensions, Lyapunov exponents, strange attractors.

Classical Electrodynamics Electrostatics, Magnetostatics, Linear media and Maxwell's equations. Time dependent Maxwell theory, wave propagation and dispersion, diffraction, scattering, radiation, relativistic covariance, and applications.

The Special Theory of Relativity The notion of covariance, Relativistic kinematics and dynamics. The covariant formulation of Electrodynamics.

The General Theory of Relativity Space, Time and Gravity in Newtonian Physics, The Equivalence Principle, The Curved Space-time of General Relativity, Geodesics, Geometry outside a spherical star, General Relativistic Effects and the classical tests of General Relativity.

2.1.4 Thermal and Statistical Physics

Thermodynamics Review of essentials, Chemical equilibrium, Thermodynamic description of second and higher order phase transitions.

Transport Phenomena Review of the essentials of Kinetic theory, Boltzmann Transport equation, The equations of hydrodynamics, Navier-Stoke's equation.

Statistical Mechanics The postulates of classical statistical mechanics, Equilibrium ensembles for classical systems, Chemical potential, The meaning of Maxwell's construction.

Quantum Statistical Mechanics The postulates of quantum statistical mechanics, Density matrix, Ideal gases in Microcanonical and Grand Canonical Ensemble, Fermi and Bose Systems.

Special Topics in thermal physics Superfluids, Ising model - Onsagar's Solution, Critical Phenomena, Heterogenous systems.

2.2 Quantum Mechanics

Formalism The Mathematical framework,Schrodinger, Heisenberg and Dirac Pictures, Invariance properties and symmetry operations.

Applications Non-Relativistic Collision theory, Perturbation, WKB and Variational methods, Semiclassical radiation theory, Identical particles, Spin.

Relativistic QM Klein-Gordan, Dirac and Proca equations and their implications.

2.2.1 Experimental Physics

1. Determination of band gap for semi conductor by four probe method.
2. Measurement of Hall coefficient of a given sample and calculation of its concentration.
3. Determination of ultrasonic velocity in some liquids at varying temperature by ultrasonic interferometer.
4. Determination of Planck's constant.
5. Determination of e/m of an electron.
6. Study of counting statistics of some radioactive samples using single channel analyser.
7. Laser based experiments.
8. Interfacing : Principles and Practices
9. Analogue and Digital Circuitry : Software, Design and Implementation
10. Pollution analysis.

3 Standard Topics

The Essential Standard Topics are marked with an asterisk.

Condensed Matter Physics $*$ Structure of simple crystals. Motion of atoms in solids and their effects on the structural, elastic, thermal, electrical, optical, acoustic and magnetic properties of solids. Electronic states: The free-electron model and the band approximation, Fermi surfaces, electronic transport. The theory of metals, dielectrics, semiconductors and superconductivity. Magnetism : Diamagnetism, Paramagnetism, Ferro, Antiferrro and Ferrimagnetism, Heisenberg Theory, Spin waves, NMR, Spin-lattice and Spin-Spin relaxation times, Bloch equations. Crystal Defects, Lasers, Mossbauer effect.

Atomic and Molecular Physics $*$ Atomic and Molecular Structure and Dynamics. Atomic: Hydrogen atom, Hartree-Fock theory, radiative transitions, photoionization, autoionization, electron-atom scattering. Fundamentals of atoms and molecules in a radiation field and techniques in Spectroscopy. A detailed study of the structure of simple atomic and

molecular systems, perturbation theory, the hydrogen and helium atoms, the hydrogen molecular ion, the hydrogen molecule, and introduction to mathematical methods of molecular physics.

Plasma Physics Basic Plasma Phenomena, Kinetic Theory, Single Particle motions in EM fields, Magnetized plasma, Magnetohydrodynamics, MHD Plasma Waves, Waves in isotropic plasma. Plasma instabilities and Non-linear interactions.

Nuclear and Elementary Particle Physics $*$ Generic properties of the atomic nuclei, nuclear models, Decay of unstable nuclei, nuclear reactions. Structure and properties of subnuclear matter: conservation laws, The Quark model and Hadron spectroscopy, Scattering and decay processes, Essential features of the fundamental interactions.

Electronics and Instrumentation Analysis of electronics found in modern instrument systems and experience in using electronic instruments. Fundamentals of analog and digital circuit design, discrete devices. Digital Electronics and Computer Interfacing: Theory and practical application of digital integrated circuits including gates, flip flops, counters, latches, and displays. Analog-to-digital and digital-to-analog conversion; parallel and serial data transfer; microprocessor fundamentals; microprocessor interfacing for data acquisition and instrument control.

4 Optional Modules

Material Science Physics of and techniques used to study the physical and chemical properties of materials. Technological applications.

Advanced Plasma Current topics of interest in plasma science e.g in space physics, fusion, solitons, plasma processing, spectroscopy, diagnostics, Plasma Kinetic theory, Statistical behavior of plasma described by distribution functions, Plasma simulation.

Quantum Field Theory Classical field theory, quantization of free fields, interacting fields, the scattering matrix, Feynman rules and diagrams, evaluation of integrals and divergences.

High Energy Physics Gauge invariance, non-Abelian gauge theories, hidden symmetries, electroweak interactions of leptons and quarks, strong interactions among quarks, string theories, and phenomenology of high-energy interactions.

Adv. Condensed Matter Computational methods in solid-state physics : Band structure calculations, Green's functions, density-functional methods, superconductivity, disordered materials.

5 Special Modules

5.1 Astrophysics and cosmology

Overview Terminology, Astronomical length, mass and time-scales, Qualitative description of interesting astronomical objects (planets to large scale structure), Evolution of structures in the universe, redshift. Astronomical measurements in different radiation bands.

Physics Consequences of Newtonian Gravity: Keplers laws and recession, flat rotation curve of galaxies and implications for dark matter; Virial theorem and simple applications; Role of gravity in different astrophysical scales. Radiative Processes : Qualitative description of which radiative processes contribute in which waveband/astrophysical system, Opacities. Gas Dynamics: EOS in different regimes, application to compact objects like white dwarfs and neutron stars. Fluid flows including supersonic flow; Supernova explosions.

Stealer Physics Basic equations of stellar structure; Stellar energy sources,Qualitative description of numerical solutions for stars of different mass, Homologous stellar models; Stellar evolution; Evolution in the HR-Diagram. Binary stars. Star clusters.

Physics of Galaxies Milky Way Galaxy; Spiral and Elliptical galaxies; Galaxies as self gravitating systems; Spiral structure; Supermassive black holes; Active galactic nuclei.

Relativity Review of Special Relativity, space-time diagrams, Lorentz metric, light cones, electrodynamics in 4 dimensional language. Introduction to general relativity (GR), equivalence principle, Curved spaces, tensor algebra, metric, affine connection, covariant derivatives, physics in curved space-time, curvature - Riemann tensor, Bianchi identities, action principle, Einstein's field equations, energy momentum tensors, energy-momentum tensor for a perfect fluid, connection with Newton's theory. gravitation as a manifestation of the curvature of space-time. Solution to Einstein's equations and their properties : Spherical symmetry, derivation of the Schwarzschild solution, test particle orbits for massive and massless particles. The three classical tests of GR, blackholes, event horizon - one way membranes, gravitational waves.

Cosmological Models Cosmological principle, Robertson-Walker metric, cosmological redshift, Hubble's law, observable quantities - luminosity and angular diameterdistances, dynamics of Friedmann-Rober tson- Walker models : Solutions of Einstein's equations for closed, open and flat universes.

Physical Cosmology and Early Universe Thermal history of the universe: Temperature-redshift relation, distribution functions in the early universe

- relativistic and non-relativistic limits. Decoupling of neutrinos and the relic neutrino background - nucleosynthesis - decoupling of matter and radiation; Cosmic microwave background radiation - inflation - origin and growth of density perturbations.

Computational Astrophysics Modeling techniques, Celestial Dynamics, N-Body Codes, Introduction to simulation techniques.

Projects / Experiments

1. To estimate the temperatures of an artificial star by photometry.
2. To study the characteristics of a CCD camera
3. To study the solar limb-darkening effect
4. To polar align an astronomical telescope.
5. To estimate the relative magnitudes of a group of stars by a CCD camera.
6. To study atmospheric extinction for different colors.
7. Differential photometry of a test star with respect to a standard star.
8. To study effective temperature of stars by $B - V$ photometry.
9. To estimate the night sky brightness with a photometer.
10. To estimate distance of moon by the parallax method.
11. Theoretical study and/or detection of 21-cm line of neutral hydrogen from our galaxy.
12. To estimate the distance of a Cepheid variable.
13. To study the variability of Delta Scuti star.
14. To study the variability of RS-CVn binaries.
15. To measure the polarization of day / moon light.

5.2 Space Science and Atmospheric Physics

Space Science Benefits and history of space activities, Current world activity in space, Remote sensing, Positioning / Navigation satellites, Geographic information systems, Solar weather phenomena, Geocoronal effect, Earth's Magnetosphere: Cosmic Rays, Effects on spacecraft, Charging and Plasma effects. Space Systems : Elements of a space mission, architecture, design, testing and operation. Spacecrafts : Navigation, guidance and attitude control, Power, Propulsion and thermal control. Space robotics: interplanetory spacecrafts and the need for autonomy, Rovers.

Environmental Physics Ecology and Biospehere : Components of ecosystems energy flow, structure and dynamics of populations and communities. Geological formation: Physical characteristics, major biological/ecological components, and significant environmental issues of the Puget Sound region

Introduction to Meteorology and Climatology Weather processes and climate, fronts and cyclones, precipitation processes, the wind systems of the world, severe storms, weather modification and global climate change.

Introduction to atmospheric physics composition and chemistry of the atmosphere, kinetic theory, the mechanics of ideal and real fluids, aerosol mechanics, atmospheric acoustics, atmospheric radiation, scattering, radiative transfer, atmospheric optics, cloud physics, and atmospheric electricity.

Physical and Dynamic Metereology Physical Metereology: global and surface energy balance; the hydrologic cycle; the influence on climate of the atmospheric and oceanic circulation; climate history, sensitivity, modeling, and natural and anthropogenic change. Dynamic Metereology : Thermodynamics and its application to planetary atmospheres, hydrostatics, fundamental concepts and laws of dynamic meteorology.

Weather analysis and forecasting Basics of weather and weather forecasting, Numerical weather prediction.

Air Pollution Basic Physics and Chemistry of Gases and atmospheric aerosols. Natural biogeochemical cycles; atmospheric photochemistry; stratospheric ozone; urban ozone and particulate matter; atmospheric visibility; acid deposition; air pollution meteorology. Aerosol sources and sinks; basic aerosol properties; single aerosol mechanics; aerosol population dynamics; atmospheric aerosol optics; aerosols and climate; aerosols and health; regional haze; aerosol measurement techniques.

Cloud and Precipitation Physics Thermodynamics of nucleation, drop growth by condensation, collection and coalescence processes, drop breakup, ice crystal growth accretion and aggregation.

Physics of High Atmospheres Physical properties of upper atmospheres, including gaseous composition, temperature and density, ozonosphere, and ionospheres, with emphasis on chemical transformations and eddy transport.

Atmospheric Measurements Theory and use of meteorological instruments; laboratory and field demonstrations and practices.

6 The interactive module

Group / Self Study Students discuss problems between themselves and work out assignments with the help of references and computational resources available in the department.

Independent / Directed study in Physics Students will work in tandem with a faculty member to study a topic of their mutual interest.

The methodology of Physics / Technical Literacy Students would have a chance to learn the operational stategies behind the conception and execution of succesful scientific projects from eminent physicists. They would also have some practice with essential communication skills as to how to write an effective technical report or present their views in a seminar.

Colloquium Series of talks presented by invited speakers spanning broad areas of physics and Science.

Seminar Lectures in any rapidly advancing specialty of physics.

Project Work Students visit research institutes to complete a month of review work under the guidance of a faculty member / work with a research group of the institute.

7 Distribution of Marks in examinations

The total marks would be computed by taking 60% from the semester examinations while the remaining 40% marks would be distributed evenly between an evaluation system based on continuous assessment and yearly viva-voce.