Presidency University
Kolkata

PHYSICS

Curriculum and Syllabus for the

Master of Science Degree Programme
Two years: Four semesters

Courses were approved by the Presidency University Council in July 2013. This curriculum applies to entrants to the PG programmes from 2013 onwards only, starting with M.Sc. entrants in August 2013.

EXCELLENCE SINCE 1817

PRESIDENCY UNIVERSITY
KOLKATA

Structure of PG (MSc) Curriculum

Semester	Module	Subject		Credits
1	1	Mathematical Physics	PHYS0701	4
	2	Classical Mechanics	PHYS0702	4
	3	Quantum Physics 1	PHYS0703	4
	4	Statistical Physics	PHYS0704	4
	5	PG Laboratory 1	PHYS0791	4
2	6	Quantum Physics 2 (including Atomic and Molecular Physics)	PHYS0801	4
	7	Classical and Relativistic Electrodynamics	PHYS0802	4
	8	Solid State Physics	PHYS0803	4
	9	Nuclear and Particle Physics	PHYS0804	4
	10	PG Laboratory 2	PHYS0891	4
3	11	Specialisation* 1 (Theory)	PHYS0901	4
	12	Specialisation* 2 (Theory)	PHYS0902	4
	13	Specialisation* 3 (PG Laboratory 3)	PHYS0992	4
	14	Elective Subject**	PHYS0904	4
	15	PG Laboratory 4	PHYS0991	4
4	16	Dissertation (equivalent to 20 credits)	PHYS1091	20

***Specialisation** -- 2 choices: A] Condensed Matter Physics, B] Astrophysics and Cosmology

** **Elective subjects** -- 4 possible choices: A] Computational Laboratory, B] Physics of nanostructured materials C] Quantum Field theory and Elementary particle physics D] Physics of Remote Sensing. (Not all of these options may be available each year)

Note: Both the Specialisation and Elective choices represent those that we initially plan to offer. Availability will vary from year to year according to the availability of staff, and, accordingly, further choices will become available in future years.

Semester 1

Module	Subject		Credits
1	Mathematical Physics	PHYS0701	4
2	Classical Mechanics	PHYS0702	4
3	Quantum Physics 1	PHYS0703	4
4	Statistical Physics	PHYS0704	4
5	PG Laboratory 1	PHYS0791	4

Paper 1
PHYS0701 Mathematical Physics (50 Lectures)

Complex Analysis **[20]**
Complex variables, Analytic functions, Cauchy -Riemann conditions, Cauchy's theorem and its corrolaries, Cauchy's integral formula, Derivatives of analytic functions, Singularities, Taylor and Laurent series, Liouville's theorem, Meromorphic functions, analytic continuation, Branch points and cuts, calculus of residues, Evaluations of integrals using residue theorem, Principal value of an integral, Asymptotic series and method of steepest descent, Conformal mappings.

Differential equations **[6]**
Sturm-Liouville theory; Hermitian operators; Completeness; Simple applications; Inhomogeneous equation: Green's functions and their evaluation.

Integral transforms **[6]**
Fourier and Laplace transforms; Bromwich integral (use of partial fractions in calculating inverse Laplace transforms); Transform of derivative and integral of a function; Solution of differential equations using integral transforms.

Group Theory **[12]**
Preliminaries; Isomorphism and homomorphism, group representation, character of representation, reduction of a representation, Rotation group and its applications, Lie groups and algebras, SU(2) and SU(3) algebras and their applications, Lorentz group.

Vector spaces **[6]**
Infinite dimensional spaces, examples, Cauchy sequences, completeness, Norms, Inner products, Hilbert spaces, Applications in Physics.

Paper 2
PHYS0702 Classical Mechanics (50 Lectures)

Preliminaries **[5]**
Variational principle and Lagrange's equations of motion – simple applications, Lagrangian for mechanical systems with dissipation and for systems subject to non-holonomic constraints, Hamiltonian formulation.

Rigid body **[8]**
Kinematics, Euler angles, Infinitesimal rotation, Motion of heavy symmetrical top with one point fixed.

Canonical transformation and Hamilton-Jacobi Theory **[12]**
Generating function, Symplectic approach, Canonical invariants, Hamilton-Jacobi theory, Action angle variables, Kepler problem – Staeckel condition, Canonical perturbation theory, Adiabatic invariants.

Continuous systems and Fields **[7]**
Lagrangian and Hamiltonian formulation for continuous systems, Symmetry and conservation principles – Noether's Theorem, Classical field theory.

Nonlinear dynamics and Classical Chaos **[18]**
Flows and maps, Fixed points and their stability, Bifurcation, Limit cycles, Integrable systems, Kolmogorov-Arnold-Moser Theorem, Lyapunov exponents, Tangent map and stability matrix.

Paper 3
PHYS0703 Quantum Physics 1 (50 Lectures)

Operator formalism in Quantum Mechanics **[6]**
Stern-Gerlach experiment, formulation of quantum mechanics in abstract space, representation of states and operators, uncertainty principle, Schroedinger and Heisenberg picture.

Quantum angular momentum **[10]**
Angular momentum algebra and its representations, matrix representation for j=1, spin,addition of two angular momenta, Clebsh-Gordan coefficients, examples,conservation laws and degeneracies associated to symmetries, continuous symmetries, space and time translations, rotations, rotation matrices, irreducible spherical tensor operators, Wigner-Eckart theorem, discrete symmetries, parity and time reversal.

Path Integral formalism in quantum mechanics **[4]**
Propagator in the coordinate representation, Aplications in simple cases, Green's function and propagator, propagator represented as Feynman's path integral

Approximation methods in quantum mechanics **[14]**

Time independent nondegenerate perturbation theory, first order and second order corrections to the energy eigenvalues, first order correction to energy eigenfunction, degenerate perturbation theory, some applications-relativistic mass corrections of hydrogen spectra, spin-orbit coupling , Zeeman and Stark effects, Variational principle, applications in harmonic oscillator and He atom to estimate the ground state energy. Excited state of He, exchange degeneracy, partial removal by first order degenerate perturbation calculation.

WKB Approximation **[4]**

Basic idea of WKB method, Construction of wave function, Connection formula, Some applications- tunnelling through barrier in simple cases, Simple explanation of alpha decay.

Time dependent perturbation theory **[12]**

Intensity of spectral lines and transition probability, Formulation of time dependent perturbation theory, Examples- constant and sinusoidal perturbation, transition probability, selection rule. Fermi's golden rule, interaction with radiation with matter, resonance. Sudden and adiabatic approximations.

Paper 4
PHYS0704 Statistical Physics (50 Lectures)

Introduction **[3]**

Introductory remarks and recapitulation, Basic needs of Statistical mechanics, Few examples, Applications in modern research.

Non ideal Classical gas **[8]**

van der Waals equation of state, Liquidgas transition, Mean field theory, Density fluctuations, Critical exponents, Cluster Integrals, MayerUrshel expansion.

Phase transitions **[12]**

Examples of phase transition and critical phenomena, Magnetic phase transitions, Ising model, Exact solution in one dimension, Peierls argument, BraggWilliams theory, Bethe-Peierls approximations, Critical exponents, Landau theory, Scaling, Universality, Basic idea of renormalization technique, Example in Ising system.

Modern computational techniques **[7]**

Basic idea of computer simulations, Few examples, Molecular dynamics, Monte-Carlo techniques, Nonequilibrium phenomena.

Quantum Statistical Mechanics **[10]**

Density Matrix, Quantum Liouville theorem, Density matrices for microcanonical, canonical and grand canonical systems, Examples: One electron in a magnetic field, A free particle in a box, A linear harmonic oscillator.

Ideal Bose and Fermi gas **[10]**
Equation of state of ideal Bose gas, Bose condensation, Superfluidity, Equation of state of ideal Fermi gas, Fermi gas at finite T, Theory of white dwarf stars, Saha Ionisation.

Paper 5
PHYS0791 Physics PG Laboratory 1

1. Lande G factor of DPPH using electron spin resonance spectrometer.
2. Velocity of ultra-sonic waves in a liquid by ultra-sonic diffraction grating
3. Saturation magnetization of ferromagnetic substance using hysteresis loop tracer.
4. Measurement of dissociation energy and anharmonicity constant using iodine vapor absorption spectrum
5. Performance of Passive pi type and T type high pass and low pass filters.
6. Design of a common emitter transistor.
7. Design and characterization of a stable multi-vibrator.
8. Michelson’s Interferometer

Semester 2

6	Quantum Physics 2 (including Atomic and Molecular Physics)	PHYS0801	4
7	Classical and Relativistic Electrodynamics	PHYS0802	4
8	Solid State Physics	PHYS0803	4
9	Nuclear and Particle Physics	PHYS0804	4
10	PG Laboratory 2	PHYS0891	4

Paper 6
PHYS0801 Quantum Physics 2 (including Atomic and molecular Physics, 50 Lectures)

Scattering theory **[12]**
Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Ramsauer-Towwnsend effect; Relation between sign of phase shift and attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering — Green’s function in scattering theory; Lippman-Schwinger equation; Born approximation; Collisions of identical particles.

Identical particles **[3]**
Identical particles, symmetry under interchange, wave functions for bosons and fermions, Slater determinant.

Relativistic Quantum Mechanics **[11]**
Klein-Gordon equation, Feynman-Stuckelberg interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; Nonrelativistic reduction; Helicity and chirality; Properties of γ matrices; Charge conjugation; Normalisation and completeness of spinors; Lorentz covariance of Dirac equation; Bilinear covariants and their transformation under parity and infinitesimal Lorentz transformation; Weyl representation and chirality projection operators.

Spectroscopy: Fine and Hyperfine structure **[4]**
Fine structure of spectral lines; Selection rules; Lamb shift. Hyperfine interaction and isotope shift; Hyperfine splitting of spectral lines; selection rules.

Many electron atom **[3]**
Equivalent and nonequivalent electrons; Energy levels and spectra; Spectroscopic terms; Hunds rule; Lande interval rule; Alkali spectra.

Molecular Electronic States **[5]**
Concept of molecular potential, Separation of electronic and nuclear wave functions, Born- Oppenheimer approximation, Electronic states of diatomic molecules, Electronic angular momenta, Approximation methods for the calculation of electronic Wave function, The LCAO approach, States for hydrogen molecular ion, Coulomb, Exchange and Overlap integral, Symmetries of electronic wave functions; Shapes of molecular orbital; and bond; Term symbol for simple molecules.

Rotation and Vibration of Molecules **[3]**
Solution of nuclear equation; Molecular rotation: Non-rigid rotator, Centrifugal distortion, Symmetric top molecules, Molecular vibrations: Harmonic oscillator and the anharmonic oscillator approximation, Morse potential.

Spectra of Diatomic Molecules **[4]**
Transition matrix elements, Vibration-rotation spectra: Pure vibrational transitions, Pure rotational transitions, Vibration-rotation transitions, Electronic transitions: Structure, Franck-Condon principle, Rotational structure of electronic transitions, Fortrat diagram, Dissociation energy of molecules, Continuous spectra, Raman transitions and Raman spectra.

Vibration of Polyatomic Molecules: Application of Group Theory **[5]**
Molecular symmetry; Matrix representation of the symmetry elements of a point group; Reducible and irreducible representations; Character tables for C2v and C3v point groups; Normal coordinates and normal modes.

Paper 7
PHYS0802 Classical and Relativistic Electrodynamics (50 Lectures)

Electrostatics and Magnetostatics **[12]**
Formal solution of the electrostatic boundary value problem with Green's function; Boundary value problems in cartesian, spherical and cylindrical Coordinates; Multipole expansion; Electrostatics of macroscopic media. Magnetostatics--- boundary value problems.

Maxwell's equations **[6]**
Vector and scalar potentials; Gauge transformations; Poynting's Theorem; Group velocity and dispersion, Kramers – Kronig relations. Resonant cavities and waveguides: Energy flow and attenuation in waveguides; Power losses in a cavity.

Relativistic Electrodynamics **[10]**
Tensors in Minkowski space, Electromagnetic field, tensor, covariance of electrodynamics, transformation of electromagnetic fields; Relativistic Lagrangian and Hamiltonian of a charged particle in an electromagnetic field; Lagrangian for the electromagnetic field; stress tensors, conservation laws.

Fields and Radiation of a localized oscillating source **[8]**
Inhomogeneous wave equation and it's solution by Green's function method; Multipole expansion of potentials and fields; Electric dipole fields and radiation; Magnetic dipole and electric quadrupole fields; Angular distribution of multipole radiation; Energy and angular momentum of multipole radiation; Multipole radiation from a linear center-fed antenna.

Radiation by moving charges **[14]**
Solution of the inhomogeneous wave equation in covariant form, invariant Green's function; Lienard-Wiechert potentials and fields for a point charge; Potentials and fields due to a charge moving with uniform velocity; Angular distribution of radiation emitted by an accelerated charge; Total power radiated by an accelerated charge; Synchroton radiation; Cherenkov radiation. Radiation damping, Abraham-Lorentz model, Scattering and absorption of radiation by an oscillator

Paper 8
PHYS0803 Solid State Physics (50 Lectures)

Crystal Structure and Diffraction from Periodic Structure: **[4]**
Reciprocal Lattice and Brillouin Zone. Bragg and Laue formulation of X ray Diffraction by a Crystal. Atomic and Crystal Structure Factors. Experimental Methods of X ray Diffraction: Laue, Rotating Crystal and Powder Diffraction Method. Electron and Neutron Diffraction by Crystals.

Lattice Dynamics **[8]**
The Harmonic Approximation, The Adiabatic Approximation, Normal Modes of a One Dimensional Monatomic Bravais Lattice, Normal Modes of a One Dimensional Monatomic Bravais Lattice with a Basis, Normal Modes of Two and Three Dimensional Monatomic Bravais Lattice. Inelastic Neutron Scattering by Phonon. Lattice Specific Heat. Anharmonic effects in Crystal Thermal Expansion and Thermal Conductivity. Mossbauer Effect.

Electron States and Band Theory of Solids **[10]**
Electron States in Crystals, General Properties of Bloch Functions, Boundary Conditions in a Finite Crystal. Density of States. Electron Band Calculations: The Tight Binding Approximation and Wannier Functions, The Nearly Free Electron Approximation and k.p Theory. Example of Band Structures (Si, Ge, GaAs & Zn). Fermi Surfaces. Cyclotron Resonance and Determination of Effective Masses. Boltzmann Transport Equation: Relaxation Time Approximation, Determination of Electrical Conductivity.

Dielectric Properties of Solids **[5]**
Static Dielectric Properties, Ferroelectrics and Piezoelectrics, Electromagnetic Waves in Solids. Frequency Dependent Polarizabilities. Dielecric relaxation. Electronic Polarizability. Free Carrier Effects. Ionic Polarizibility.

Magnetic Properties of Solids **[10]**
Fundamental Concepts, Diamagnetism and Paramagnetism (Quantum Theory). The Exchange Interaction, Exchange Interaction between Free Electrons, Spontaneous Magnetization and Ferromagnetism. The Band Model of Ferromagnetism, The Temperature Behaviour of a Ferromagnet in the Band Model. Ferromagnetic Coupling for Localized electrons, Ferrimagnetism and Antiferromagnetism. Spin Waves. Magnetic Resonance Phenomena.

Superconductivity **[8]**
Some fundamental Phenomena Associated with Superconductivity. Phenomenological Description by Means of the London Equation. The BCS Ground State. Consequences of the BCS Theory and Comparison with Experimental Results. Supercurrents and Critical Currents. Coherence of the BCS Ground State and the Meissner-Ochsenfeld Effect. Quantization of Magnetic Flux. Type-II Superconductors. Novel High Temperature superconductors. One-Electron Tunneling in Superconductor Junctions,. Cooper Pair Tunneling – The Josephson Effect.

Defects in Solids and Optical Properties: **[5]**
Frenkel and Schottky Defects, Defects in Growth of Crystals. The Role of Dislocations in Plastic Deformation and Crystal Growth. Colour Centers and Photoconductivity. Luminescence and Phophorescence. Alloy, Order-Disorder Phenomena, Bragg-Williams Theory.

Paper 9
Phys0804 Nuclear and Particle Physics (50 Lectures)

Nuclear structure and interaction **[13]**
Properties of nuclei - size, shape, charge distribution, binding energy, angular momentum, parity, magnetic dipole and quadrupole moment, Nuclear models – Fermi gas model, spherical shell model. Collective model – vibration and rotation, Nilsson's model, Schrödinger equation and its solution for ground state of deuteron, Experimental results on low energy n-p and p-p scattering, spin dependence of nuclear forces, Necessity of tensor forces, Isospin symmetry, Exchange interaction.

Nuclear decay and Nuclear Reaction **[17]**
Beta decay and electron capture, Fermi's theory, Selection rules (Fermi, Gamow-Teller), 2 component theory and double beta decay, Multipole radiation, selection rules and transition probabilities for gamma decay, internal conversion, Nuclear reaction – compound nucleus formation and break-up, Resonance scattering and reaction, Breit-Wigner dispersion relation, Optical model, Transfer reaction, Spontaneous fission – mass and energy distribution of fragments, elementary theory based on barrier penetration, photofission.

Elementary particle physics **[20]**
Interaction and fields, Particle classification – hadron and lepton, Quantum numbers, invariance principles and conservation laws, Quark model of hadrons. Basic discussion of the Standard Model including brief elucidation of the key experiments that led to the development of the model. Hints of departures from the Standard Model, e.g. the Higgs particle.

Paper 10
Phys0891 Physics PG Laboratory 2

1. Refractive Index of a thin film by Michelson's interferometer.
2. Thickness of a thin film by Jamin interferometer.
3. Fabry Perrot interferometer.
4. Calibration of audio frequency oscillator (Lissajous figure method + velocity of sound method).
5. Velocity of ultra-sonic wave in a liquid by ultra-sonic interferometer.
6. Determination of the specific charge of an electron by modified Thomson's method.
7. Saw-tooth wave generator
8. Active RC filter characterization
9. Amplitude modulation and demodulation.

Semester 3

11	Specialisation* 1 (Theory)	PHYS0901	4
12	Specialisation* 2 (Theory)	PHYS0902	4
13	Specialisation* 3 (PG Laboratory 3)	PHYS0992	4
14	Elective Subject**	PHYS0904	4
15	PG Laboratory 4	PHYS0991	4

Paper 11-13
PHYS0901, PHYS0902, PHYS0992 Specialisation

Two choices:

A) Condensed Matter Physics
B) Astrophysics and Cosmology

Each option will consist of two theoretical papers (Papers 11-12) and an Advanced Laboratory (PG Laboratory 3, Paper 13).

Specialisation Option A: Condensed Matter Physics

Paper 11A
Condensed Matter Physics 1 (50 Lectures)

Fundamentals of Many-Electron Systems : Hartree-Fock Theory [12]

The Basic Hamiltonian in a Solid – Electronic and Ionic Parts. The Adiabatic Approximation. Single Particle Approximation of the Many Electron System: Single Product and Determinantal Wave Functions, Matrix Elements of one and two particle Operators. The Hatree Fock (HF) Theory. The HF Equation. Exchange Interaction and Exchange Hole, Koopmans Theorem. The occupation Number Representation – The Many Electrons Hamiltonian in Occupation Number Representation. The HF Ground State Energy.

The Interacting Free Electron Gas : Quasi Electrons and Plasmon [12]

The HF Approximation of the Free Electron Gas. Single Particle Energy Levels, the Ground state energy. Calculation of the Ground State Energy. Cohesive Energy in Metals. Screening and Plasmons. Experimental Observations of Plasmons. The Dielectric Function of the Electron Gas. Friedel Oscillations. Landau's Quasi Particle Theory of Fermi Liquid. Strongly Colelated Electron Gas. Mott Transition.

Coherence and Correlation [8]

Types of Coherence. Density Matrix Formalism. Quantum Coherent Effects. Correlation Functions and Noise. Particle Particle Correlation. The Fluctuation – Dissipation Theorem. Current Fluctuations and the Nyquist Formula. The Kubo Formula and Many Body Theory of Metals. Mesoscopic Effects.

Spin and Magnetic System: **[10]**
Overview of Magnetic Properties. The Ising Model: Zero External Magnetic Field; Spontaneous Symmetry Breaking, External Magnetic Field Hysteresis. Critical Fluctuations: Other magnetic models, Multicritical behaviour, Metamagnets, Critical Exponents and Magnetic Susceptibility, Landau Coarse Graining Theory. Renormalization Group Methods, Spin Waves and Goldstone Bosons. Spin Spin Interactions: Ferromagnetic Instability, Localized States and RKKY Exchange Interactions. Spin Flip and Spin Dephasing.

Superconductivity Phenomena: **[8]**
Constructing Bosons from Fermions. Electron Electron Interaction via Lattice Cooper Pairs, BCS Wave function. Excitation Spectrum of a Superconductor. Ginzburg Landau Theory and London Equation. Meissner Effect. TypeII Super Conductors Characteristics Length. Josephson Effect. High Temperature Super Conductprs.

Paper 12A
Condensed Matter Physics 2 (50 Lectures)

Interactions of Quasiparticles & Transport Phenomena in Solids: **[8]**
Electron Phonon Interactions: Deformation Potential Scattering, Piezoelectric Scattering, Frohlich Scattering. Electron Photon Interactions: Optical Transitions between Semiconductor Bands, Direct & Indirect Transitions, Joint Density of States. Phonon Phonon Interactions. Electron Electron Interactions: Semiclassical Estimation of Screening Length. The Relaxation Time Approximation and Diffussion Equation. The Boltzmann Transport equation. Thermal Conductivity, Electrical Conductivity and Magnetoresistance in Two Band Model.

Electronic Quasi particles in Solids: **[8]**
Quasiparticles, Effective Mass, Basic Behaviour of Semiconductors, Band Bending and Hetero junctions. Quantum Confinement: Density of States in Quantum confined Systems (Low dimensional systems), Excitons in Quantum Structures, Super lattices, Disorder in Quantum Confined Systems, Two Dimensional Electron Gas. Landau Levels and Quasi articles in Magnetic Field: Density of States in Landau Levels, De Hass van Alphen and Shubnikov De Hass Oscillations, Integer Quantum Hall Effect, Fractional Quantum Hall Effect and Higher – Order Quasi particles. III. The Complex Susceptibility & dielectric properties of materials.

Dielectric Properties of Materials: **[6]**
Microscopic view of the Dielectric Constant. Kramers-Kronig Relation. The Quantum Mechanical Oscillator, Dielectric Functions. Polaritons. Nonlinear Optics and Photon Photon Interactions: Second Harmonic Generation and Three Wave Mixing, Higher Order Effects. Acousto Optics and Phonon Phonon Interactions. Raman Scattering.

Growth, Characterization and Phase Diagrams of Materials **[9]**
Classification of materials (crystalline, amorphous, nanomaterials, ceramics, liquid crystals and polymers). Growth: Processes for crystal growth, doping techniques of elemental and compound semiconductors; Growth processes (Physical and Chemical Vapor Deposition) and fundamentals of thin films; Recent developments in material processes. Characterization: Diffraction techniques – X ray Diffraction, Neutron Diffraction; Electron Microscopy – Transmission Electron and Scanning Electron Microscopy; Optical methods – FTIR, Raman Spectroscopy, UV – VIS – NIR – IR; Surface techniques – AFM, STM, Chemical ESCA, AES and RBS; Thermal methods – DTA, TGA, DSC; Other techniques – ESR, NMR, Mossbauer and Positron annihilation. Phase Diagrams: Phase Rule, Single component, Binary systems and Lever Rule.

Liquid Crystals: **[4]**
Isotropic. Nematic and Cholesteric Phases. Smectics A and –C. Hexatic Phases. Discotic Phases. Lyotropic Liquid Crystals and micro emulsions.

NonCrystalline Materials **[7]**
Microstructure and imperfections. Diffusion in solids and related phenomena. Noncrystalline and glassy materials – Structure, Thermodynamics, Glass transition and related models, tunneling states, Specific heat estimation, Two – level system. Amorphous semiconductors – Electrical properties, magnetic properties, switching and device applications.

Nanostructure Materials and Carbon NanoTubes: **[8]**
Properties of Individual Nanoparticles. Quantum Wells, Wires and Dots. Size and Dimensionality Effects. Preparation and Characterization of Quantum nanostructures. Applications of nanostructures. Self Assembly and catalysis. Carbon Nanostructures: carbon Clusters & Fullerenes. Carbon Nanotubes: fabrication, Structurs & Electronic Properties, Application of carbon Nanotubes. Nano-structured Ferromagnetism, Nanocarbon Ferromagnets, Giant and Colossal Magnetoresistance. Ferrofluids.

Paper 13A
Condensed Matter Physics Experiments**

1. Determination of Space Group and Crystal Structure of a Single Crystal Material by Laue Diffraction Method.
2. Determination of Crystal Structure and Lattice Parameters of a Polycrystalline Material by Powder Diffraction (Debye Scherrer) Method.
3. Determination of Hall Effect & Magnetoresistance of Polycrystalline Bismuth Sample at RT.
4. Determination of Magnetic Susceptibility of Paramagnetic Salts by Guoy Balance Method.
5. Determination of AC Conductivity and Dielectric Constants of Composites Materials by LCR Bridge.

6. Study of Dielectric Constants of Ferroelectric Crystals at Elevated Temperatures and determine the Curie Temperature.
7. Study of F Centers of Xray Irradiated Alkali Halides (KCl & KBr) Samples.
8. Study of the Nature of Band Gap and Determination of Optical Constants (n, k) of Semiconductor (Crystalline and Amorphous) Thin Films using UV-VIS (Dual and Single beam) Spectrophotometer.
9. FTIR Study of Si Based Oxide/ Carbon Nano Composites.
10.Study of the variation of Hall Coefficient of a given extrinsic semiconductor as a function of temperature using Temperature dependence Hall – effect setup.
11.Study of the electrical properties of given thin films of different materials (metal, insulator and semiconductor) using Four – Probe Setup.
12. Measurement of electrical resistivity of superconductors at low temperature.

******Students will do 6-8 experiments among these.

Specialisation Option B: Astrophysics and Cosmology

Paper 11B
Astrophysics and Cosmology 1 (50 Lectures)

Astronomical Observations [16]

Our current understanding of the Universe (broad idea of cosmology, galaxy clusters, galaxies, stars, and planets), Astronomical distance scale (AU, light year, parsec, mega-parsec) and mass scale, Refracting and reflecting telescopes, Concept of angular size and its relation to physical size, Diffraction limit, Astronomical seeing, Need for Space telescopes, Basic observational techniques in optical, radio and high-energy (X-ray/gamma-ray) astronomy, outlines of spectroscopic and polarimetric observations, Stellar parameters (mass, radius, temperature) from binary systems, Extrasolar planets, Continuous, emission, and absorption spectra, Formation of spectral lines, HR diagram, Main sequence.

Stellar Astrophysics [18]

Virial theorem, Hydrostatic equilibrium, Concept of Opacity, Stellar energy sources, Solar neutrino, Jeans Criterion, Interstellar medium, Formation of protostars, evolution of stars before, during and after their location on the main sequence, HII region, Stromgren sphere, Supernovae, Stellar Pulsation, Degeneracy pressure, White dwarfs, Chandrasekhar limit, Neutron stars, Pulsars, Black holes, Close binary systems, accretion disks.

Galactic Astrophysics [10]

Spiral, elliptical and irregular galaxies (rotation, spiral structure, dark matter, Faber-Jackson law), Interaction and evolution of galaxies (evolutionary relation of spirals and ellipticals), Super-massive black hole (MBH vs. Mbulge, Black hole-galaxy co-evolution), Morphology, Kinematics, Galactic centre.

Extragalactic Astrophysics **[6]**
Galaxy clusters, Cosmic distance ladder (Parallax, Cepheid variables, Hubble's law, Type IA supernovae), Observations of active galaxies all over the electromagnetic spectrum, Unification model, Importance in galaxy formation and evolution, Gamma-ray bursts.

Paper 12B
Astrophysics and Cosmology 2 (50 Lectures)

Foundations of General Relativity and Curved Spacetime (25 lectures)

Basic concepts of Relativity **[3]**
Need for GTR, introduction to Einstein's theory of relativity, principle of equivalence, connection between gravity and geometry,

Tensors **[5]**
Metric tensor and its properties, concept of curved space spacetime, Tensor algebra, Tensor calculus, Covariant differentiation, parallel transport; Riemann curvature tensor; geodesics

Einstein's Field Equations **[9]**
Field Equations and Schwarzschild Metric; Einstein's equations for weak gravitational fields, the Newtonian limit; derivation of Schwarzschild metric. Nature of R=2M surfaces, concept of black holes; particle and photon trajectories in Schwarzschild metric.

Experimental tests of Einstein's Theory **[4]**
Gravitational redshift, the precession of the perihelion of Mercury, bending of light

Gravitational Waves **[4]**
Linearized equations and plane wave solutions, radiation from gravity waves, cosmic sources of gravity waves, detection methods of gravity waves

Cosmology (25 lectures)

Standard Model of Cosmology **[10]**
Historical development of cosmology, Observational triumphs of cosmology, Olber's paradox, Hubble's law and the expanding Universe, Big Bang theory, redshift, scale factor, FRW metric, Cosmological principle, homogeneity and isotropy, Newtonian cosmology, Friedmann equation, conservation and acceleration equations, different components of the Universe, equation of states, multi-component Universe, Distance measures in cosmology

The Cosmic Microwave Background **[5]**
Recombination and decoupling of photons, surface of last scattering, temperature fluctuations in the CMB, acoustic oscillations, primary and secondary temperature anisotropies, measuring the CMB temperature anisotropy, CMB as a probe of cosmology

Big Bang Nucleosynthesis **[2]**
Nuclear statistical equilibrium, initial conditions, production of light elements, primordial abundances: predictions and observations, baryon asymmetry, Shakharov criterion

Structure Formation in the Universe **[5]**
Gravitational instability, linear perturbation theory, initial conditions, matter power spectrum, large scale structure in the Universe, 2-pt correlation function, observations of large scale structures, baryon acoustic oscillations, dark matter halos, hot versus cold dark matter, cosmological simulations

Inflationary Paradigm **[3]**
Problems with the standard model, flatness, horizon and monopole problems, Inflation as a viable solution, scalar field dynamics, conditions for slow-roll inflation, reheating, observational status of inflationary models.

Paper 13B
Astrophysics Laboratory

Data Analysis Projects
1. Determining parameters of Extra-Solar planets.
2. Main sequence fitting of a star cluster.
3. Statistics of the Cosmic Microwave Background
4. Galaxy Spectral Fitting

Experimental Projects
1. Solar Limb Darkening
2. Characterizing radio antennae.
3. Characterization of Charged Coupled Device
4. Faraday Rotation

Paper 14
PHYS0904 ELECTIVE SUBJECTS

Paper 14A: Computational Laboratory

I. FORTRAN (or C or C++ or Python) Language (5 Lectures) (in Laboratory):

Preparatory courses of writing computer programs (in Computer Laboratory)

II. Numerical mathematical analysis (15 Lectures) (in theory classroom):

Numerical (mathematical) methods for (i) Basic idea of Interpolation, Lagranges and Newton-Gregory type interpolation (ii) Derivations of the formulae for numerical differentiation (iii) Analysis of errors in different methods (iv) Derivations of the formulae for numerical Integration, Trapezoidal rule, Simpson's rule, Gauss quadrature (v) Analysis of errors (vi) Integration by statistical methods, simple sampling, intelligent sampling (vii) Systematic derivations of the numerical methods of solving ordinary differential equations, Euler method, Its modification, Runge-Kutta method, Taylor's method (viii) Method of solving partial differential equations, solution of Laplace's equation on the lattice, iteration method. (ix) Elementary idea of computer simulation, Monte Carlo techniques, Molecular dynamics, Cellular automata.

III. Assigned problems in computer laboratory (30 computer lab sessions):

(i) Interpolation by using difference table and divided difference table
(ii) Derivative by forward difference and central difference method
(iii) Integration by Gauss quadrature method
(iv) Integration by statistical method (simple and intelligent sampling)
(v) Solving ODE by Runge-Kutta and Taylor method
(vi) Solving wave equation and Laplace equation in two dimensions
(vii) Example of Monte Carlo technique
(viii) Example of Molecular dynamics
(ix) Example of cellular automata
(x) Advanced topics in Astrophysics

Paper 14B: Physics of Nanostructured materials

Introduction to Nanostructured Materials [8]

Introduction. Size dependence of properties. Metal nanoclusters, bulk to nanotransition, semiconducting nanoparticles. Carbon nanostructures: carbon clusters, carbon nanotubes (CNT), fullerenes and graphenes, nanocomposites and hybrids.

Growth, fabrication and measurement techniques for nanostructures [12]

Spontaneous formation and ordering of nanostructures. Top-down and bottom-up approach and templates. Methods of synthesis of nanostructures: RF plasma, chemical methods, Sol-Gel technique, electrochemical methods, thermolysis, pulsed laser methods, Physical vapor deposition, ball milling, vapour-liquid-solid (VLS) method. Methods of carbon nanotube growth. Nanostructures determination: atomic structures, X-ray diffraction and crystallography, small angle X- ray scattering (SAXS), particle size determination, surface structure. Microscopy: Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Field Ion Microscopy (FIM), Scanning Tunneling Electron Microscopy (STEM). Spectroscopy: Infrared and Raman spectroscopy, Photoluminescence, Photoemission and X-ray spectroscopy. Magnetic Resonance.

Electron transport in semiconductors and nanostructures **[14]**
Time and length scales of electrons in solids. Statistics of electrons in solids and nanostructures. The density of states (DOS) of electrons in nanostructures. Electron transport in nanostructures: dissipative transport in short structures, hot electrons, quantum ballistic transport and Landauer formula, single electron transport. Electrons in traditional low-dimentional structures (quantum wells, quantum wires & quantum dots).

Nanostructured ferromagnetism: **[6]**
Magnetic properties of nanostructured materials. Dynamics of nanomagnets. Dilute magnetic semiconductor (DMS), Spintronics. Nanocarbon ferromagnets. Ferrofluids. Super paramagnetism. Ferromagnetic resonance (FMR).

Self-assembly and catalysis: **[4]**
Self-assembly: process of self-assembly, semiconductor islands, monolayers. Catalysis: nature of catalysis, surface area of nanoparticles, porous materials, pillared clays and colloids.

Applications and future of nanomaterials: **[6]**
Nanoelectronics: single electron transistor, resonant tunneling diodes. Micro and nano-electromechanical systems. Nanosensors. Nanocatalysis. Role of nanomaterials in food and agriculture industry & water treatment. Nano-medical applications. Defence and space applications. Nanomaterials for non conventional energy source and energy storage.

Paper 14C: Quantum Field theory and its applications

Formalism (35 lectures)

Preliminaries **[5]**
Classical Field Theory, Euler Lagrange equation, Hamiltonian formalism, Noether's Theorem, Lorentz and Poincare symmetries.

Free Field **[7]**
Canonical quantization of scalar and complex scalar fields, Canonical quantization of spinor field, Feynman propagators.

Interacting Field **[7]**
The interaction picture, Time evolution operator, S-matrix, Wick's Theorem, Feynman diagram

Electromagnetic Field **[7]**
Fourier decomposition of the field, Gupta-Bleuler method, Feynman propagator, Canonical quantization of the photon field, Feynman rules of Quantum Electrodynamics.

Renormalization **[9]**

Degree of divergence of a Feynman diagram, Ward-Takahashi identity, General forms of divergent amplitudes, Regularization, Counterterms, Renormalization - applications to Quantum Electrodynamics.

Applications (15 lectures)

Different courses of applications will be offered in each year, from

1. Field Theories in Condensed Matter Physics

2. Cross-sections and decay rates in Particle Physics and Astroparticle Physics

3. Field theories in Cosmology

Paper 14D: Physics of Remote Sensing

Introduction **[2]**

Overview of the remote sensing processes, passive and active sensing techniques, Why observe earth from space? Airborne and spaceborne systems, concept of signatures.

Electromagnetic wave and interaction with matter **[7]**

Different ranges of electromagnetic spectrum useful to remote sensing, characteristics of solar radiation, angular distribution of radiation, polarization, absorption, dielectric constants and refractive indices of materials, surface scattering, Lambertian surface, BRDF, volume scattering and volume absorption, radiative transfer equation, reflection and emission from materials in visible, near-infrared, thermal infrared and microwave region.

Interaction of electromagnetic waves with the atmosphere **[4]**

Composition and structure of atmosphere, molecular absorption and scattering, microscopic (aerosol) and macroscopic (rain, cloud, fog etc.) particles, ionosphere, turbulence, atmospheric sounding, estimation of greenhouse gases.

Remote Sensors and instrumentation **[8]**

Principles of radiometry, physical basis of spectral signatures, surface characteristics and observation geometry, overview of remote sensors: classification, selection of parameters, resolutions and field of view, definition of bands, optomechanical and pushbroom scanner, dwell time, hyperspectral sensor, high spatial resolution imaging systems, brief idea on spaceborne and airborne sensors like MSS, TM, LISS, SPOT, CZCS, WiFS, OCM, MODIS, AVHRR, AVIRIS and Hyperion, lidar, microwave sensors, principle of radar and microwave radiometer.

Space platforms **[4]**
Principles of satellite motion, launching and locating a satellite in space, types of orbit, orbital perturbations, geosynchronous and geostationary orbits, sunsynchronous orbit, brief idea of satellite systems like LANDSAT, IRS, METEOSAT and ENVISAT, principle of satellite communication.

Data reception and analysis **[6]**
Multispectral and hyperspectral imagery, data product formats, sources of errors in received data and correction, georeferencing, idea of photogrammetry, colour triangle, false colour composite, visual image analysis, fundamentals of digital image processing: image enhancement, histogram equalization, band combination and definition of indices, classification techniques, frequency domain analysis, digital elevation model, advanced techniques, e.g. fuzzy logic and artificial neural network.

Geographic Information Systems **[3]**
Need of GIS, data entry and data structures, raster and vector data analysis, data integration and modelling

Some applications of remote sensing **[8]**
(a) Plant science: precision agriculture, vegetation indices, leaf area index, forestry type and density mapping, land cover/use mapping
(b) Earth and hydrospheric science: spectral observation of rocks and minerals, spectral changes with water depth, ocean and coastal researches, investigation on snow and glacier, fisheries and wetland management
(c) Atmosphere and others, future trends

Demonstration classes **[8]**
(i) Experiment on spectroradiometry to study spectral signatures, radiance etc.
(ii) To handle multispectral satellite data with computer software.
(iii) Image processing techniques: enhancement, spatial filtering, classification etc.
(iv) Handling of hyperspectral image.

Paper 15
PHYS0991 Physics PG Laboratory 4

The contents for this laboratory will be submitted for Council approval at a later date.

Semester 4

16	Dissertation (equivalent to 20 credits)	PHYS1091	20

Paper 16
Dissertation

1. Research Methodology and Skills (12 lectures)

1. Analytical Techniques
2. Bibliography Search
3. Writing and Speaking Skills

The acquired skills will be examined in the activities outlined below.

1. Dissertation

The student is expected to carry out an independent research project under the supervision of a member of faculty. Supervision may be arranged jointly with an equivalent academic at another institution, and the research may be carried out off campus, as long as the duration of the semester is spent exclusively working on the research project.

A) At the end of the second week of research, the student will submit a research proposal (less than 1000 words) with an estimated timeline for its various components. This will carry 10% of the marks and will have to be approved by the Physics Academic Board.
B) Towards the end of the Semester, on a prescribed date, the student will submit a dissertation describing the research and its principal results (less than 15,000 words, excluding Appendices, tables and figures). This will be examined by two members of faculty, including the faculty supervisor, and will carry 60% of the marks;
C) give a talk on the subject before an audience consisting of students and faculty, which will be evaluated, carrying 10% of the marks of the module.
D) appear before a viva voce examination before a board of three members, of which one will be the faculty supervisor. This will carry 20% of the marks of the module.