**Department of Physics, Presidency University**  
Syllabus (w. e. f. July 2017) for 2-Year 4-Semester M. Sc. Degree Programme

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<td>B] Introduction to Astrophysics</td>
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**Not all electives will be offered every year**)
PHYS-0701: Mathematical Methods (50 Lectures)

**Complex Analysis** [16]
Complex variables, Analytic functions, Cauchy -Riemann conditions, Cauchy's theorem, Cauchy's integral formula, Derivatives of analytic functions, Singularities, Taylor and Laurent series, Branch points and cuts, calculus of residues, Evaluations of integrals using residue theorem, Principal value of an integral. Application of complex variables: Complex potentials, application of conformal transformations.

**Differential Equations** [10]
Sturm-Liouville theory; Hermitian operators; Completeness; Simple applications; Inhomogeneous equation: Introduction to Green’s functions and its application.

**Integral Transforms** [8]
Fourier and Laplace transforms; Transform of derivative and integral of a function; Solution of partial differential equations using integral transforms.

**Group Theory** [10]
Preliminaries; Isomorphism and homomorphism, group representation, Character of representation, Finite groups, Reduction of a representation, Rotation group and its applications, Permutation group, Introduction to continuous groups.

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

PHYS-0702: Classical Mechanics: Particles and Fields (50 Lectures)

**Preliminaries** [10]
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, Small Oscillations

**Rigid Body** [12]
Kinematics, Euler angles, Infinitesimal rotation, Motion of heavy symmetrical top with one point fixed, other applications.

**Canonical Transformation and Hamilton-Jacobi Theory** [14]
Generating function, Poisson bracket, Canonical invariants, Hamilton-Jacobi theory, Action angle variables, Kepler problem.

**Continuous Systems and Fields** [10]
Introduction to tensors, Lagrangian and Hamiltonian formulation for continuous systems, Symmetry and conservation principles – Noether's Theorem, Classical field theory

**Nonlinear Dynamics and Classical Chaos** [4]
Phase space dynamics, Stability analysis
PHYS-0703: Quantum Physics-I (50 Lectures)

Operator formalism in Quantum Mechanics

Quantum angular momentum
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.

Approximate Methods in Quantum Mechanics
Time independent non-degenerate 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 and its applications. Basic idea of WKB method, Construction of wave function, Connection formula, Some applications (e.g., tunnelling through barrier in simple cases, Simple explanation of alpha decay, Intensity of spectral lines and transition probability), Formulation of time dependent perturbation theory, Examples, transition probability, Rabi oscillations, selection rule. Fermi's golden rule, Applications

Identical particles
Identical particles, symmetry under interchange, wave functions for bosons and fermions, Slater determinant, Pauli exclusion principle, 2-particle system (e.g., He atom).

PHYS-0791: PG-Lab-I

The Following Experiments are part of the lab
1. Lande G factor of DPPH using electron spin resonance spectrometer
2. Performance of high pass and low pass filters
3. Michelson’s Interferometer
4. Saturation magnetization of ferromagnetic substance using hysteresis loop tracer
5. Characteristics of optical fibre

PHYS-0792: PG-Lab-II

A) Experiments
1. Muon detector
2. Noise Fundamentals
3. Fabry Perrot interferometer

**B] Data Analyses and Statistical Techniques**

2. Estimates of mean and error, chi-square test.
3. Least square fit, goodness of fit, hypothesis testing.
5. Plotting of data and preliminary analyses.

**PHYS-0801: Statistical Mechanics (50 Lectures)**

**Fundamentals of Statistical Mechanics**

Introduction; thermalization, ergodicity, Microcanonical Ensemble; Entropy and the Second Law; Temperature; Canonical Ensemble; Energy Fluctuations; Chemical Potential; Grand Canonical Ensemble, applications.

**Classical and Quantum Gas**

Classical Partition Functions; Ideal Gas; Equipartition; Maxwell Distribution; Diatomic Gas; Interactions; van der Waals Equation of State; Cluster Integrals and Mayer-Urshel Expansion, Density of States; Applications, Density matrix formalism, Bose-Einstein Distribution and Bose-Einstein Condensation; Fermi-Dirac Distribution and ideal Bose and Fermi Gas, Applications (e.g., Saha Equation and its application in Stellar Astrophysics, Statistical Mechanics and theory of compact objects, Cold Atoms, Boltzmann equation and early Universe Cosmology, interdisciplinary applications).

**Phase transitions**

van der Waals equation revisited; Ising Model; Exact solution in one-dimension, Mean Field Theory; Critical Exponents; Low Temperature Expansion and Peierls Droplets; High Temperature Expansion; Landau Theory; Landau-Ginzburg Theory; Fluctuations and Correlations; Athermal phase transition, Non-equilibrium phenomena

**PHYS-0802: Classical Electrodynamics (50 lectures)**

**Basics**

Concept of Fields - Scalar, vector and tensor fields; Maxwell's equations for electrostatics and magnetostatics: solutions; role of rotational symmetry; electrostatics - Green's functions, multipole expansions, boundary value problems; magnetostatics - Biot-Savart relation, magnetic moments, Larmor precession; action principle for test charges in electromagnetic potentials and Lorentz force equation.

**Relativistic Formulation of Electrodynamics**

Vacuum Maxwell equations for potentials and their symmetries; origin of special relativity and Lorentz invariance; relativistic energy and momentum, relativistic kinematics; relativistically covariant form of Maxwell's equations for potentials: EM waves, propagation in inhomegenous media, transversality and gauge fixing issues; polarization including partial polarization, Stokes parameters, covariant form of Lorentz force equation.
Radiation
Lienard-Wiechert potentials, dipole radiator, radiated power spectrum, multipole radiation; Scattering of electromagnetic waves, Angular distribution of radiation emitted by an accelerated charge; Total power radiated by an accelerated charge; Synchrotron radiation, Radiation Reaction of point like charges and fundamental issues of classical electromagnetism.

**PHYS-0803: Condensed Matter Physics (50 Lectures)**

**Electron States and Band Theory of Solids**

**Dynamics of Atoms in Crystals and Phonons**

**Dielectric and Optical Properties of Solids**

**Magnetic Properties of Solids**

**Superconductivity**
Superconductors. One-Electron Tunneling in Superconductor Junctions, Cooper Pair Tunneling – The Josephson Effect, Applications

**Liquid Crystals** [6]

**PHYS-0891: PG-Lab III (Computational Techniques)**

A] **FORTRAN (or C or C++ or Python) Language** [10]
Preparatory courses of writing computer programs

B] **Numerical mathematical analysis** [15]

C] **Assigned problems in computer laboratory** [25]
(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

**PHYS-0892: PG-Lab-IV**

The Following Experiments are part of the lab

1. Determination of the dissociation energy and anharmonicity constant of the iodine molecule by analysing its absorption spectrum
2. Study of Zeeman pattern of the green line of mercury
3. Calibration of an AF Oscillator
4. Measuring charge to mass ratio (e/m) of electron
5. Construction of sawtooth wave generator using UJT
6. Measuring structural parameters of given helical sample using diffraction pattern
7. Velocity of ultra-sonic waves in a liquid by ultra-sonic diffraction grating
8. Kerr effect

**PHYS-0901: Quantum Physics-II (50 Lectures)**

**Scattering theory**
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-Townsend effect; Scattering by a rigid sphere and square well; Regge poles, Coulomb scattering; Born approximation; Formal theory of scattering — Green’s function in scattering theory; Lippman-Schwinger equation; Collisions of identical particles, applications

**Relativistic Quantum Theory**
Klein-Gordon equation, Feynman-Stuckelberg interpretation of negative energy states and concept of antiparticles; Preliminaries of free quantum field theory, Canonical quantization of scalar and complex scalar fields, Feynman propagators. Dirac equation, Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; Non relativistic reduction; Helicity and chirality; Properties of $\gamma$ matrices; Charge conjugation; Normalisation and completeness of spinors; Bilinear covariants and their transformation under parity and infinitesimal Lorentz transformation; Weyl representation and chirality projection operators, Quantisation of spinor fields.

**PHYS-0902-A: Advanced Condensed Matter Physics-I (50 Lectures)**

**Fundamentals of Many-Electron Systems: Hartree-Fock Theory**

**The Interacting Free Electron Gas: Quasi Electrons and Plasmon**

**Spin and Magnetic System**
Overview of Magnetic Properties. The Ising Model: Zero External Magnetic Field; Spontaneous Symmetry Breaking, External Magnetic Field Hysteresis. Critical Fluctuations: Other magnetic models, Multi critical behaviour, Metamagnets, Critical

Superconductivity Phenomena

PHYS-0902-B: Introduction to Astrophysics (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, megaparsec) 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 (Xray/ 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. M_bulge, Black hole-galaxy coevolution), 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.

PHYS-0903-A: Advanced Condensed Matter Physics-II
Interactions of Quasiparticles & Transport Phenomena in Solids[12]

Electronic Quasi particles in Solids[8]

Realistic Calculations in Solids[8]
Numerical Methods: Pseudo potentials and Orthogonalized Planes Waves (OPW), Linear Combination of Atomic Orbitals (LCAO), Plane Waves, Linear Augmented Plane Waves (LAPW).

Non-Crystalline Materials [10]

Nanoscale Physics [12]

PHYS-0903-B: General Relativity and Cosmology
(50 Lectures)

Foundations of General Relativity and Curved Spacetime [25]
Basic concepts of Relativity, Need for GR, introduction to Einstein’s theory of relativity, principle of equivalence, connection between gravity and geometry. Tensors: 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: 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: Gravitational redshift, the precession of the perihelion of Mercury, bending of light, Gravitational Waves: Linearized equations and plane wave solutions, radiation from gravity waves, cosmic sources of gravity waves, detection methods of gravity waves.
**Cosmology**

Standard Model of Cosmology: 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, Distance measures in cosmology, the Cosmic Microwave Background: 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, Structure Formation in the Universe 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, hot versus cold dark matter, cosmological simulations Inflationary Paradigm

**PHYS-0991: Project-I**
Review of Literature/Experimental Technique

**PHYS-0992: Project-II**
Formulation of Project Proposal

**PHYS-1001-A: Quantum Field Theory (50 Lectures)**

**Interacting fields and Feynman Diagrams** [8]
The interaction picture, Time evolution operator, S-matrix, Wick’s Theorem, Feynman diagram.

**Elementary processes of quantum electrodynamics** [8]
Elementary scattering processes, Bound States, Crossing Symmetry, Mandelstam Variables

**Radiative corrections** [10]
Introduction and some formal developments, soft Bremsstrahlung, electron vertex function; Field strength renormalization, LSZ reduction formula, Optical theorem, Ward Takahashi identity, renormalization of electron mass and charge.

**Functional methods** [14]
Path integrals, functional quantizations, quantization of the electromagnetic field, symmetries in functional formalism; Renormalization: systematics of renormalization, Spontaneous symmetry breaking.

**Quantum Fields in curved spacetime** [10]
Scalar field and its quantization in curved spacetime, Bogolyubov transformations and the particle concept, choice of the vacuum state; quantum scalar fields in FRW universe.
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]

Electron transport in semiconductors and nanostructures [14]

Nanostructured ferromagnetism [6]

Self-assembly and catalysis [4]

Applications and future of nanomaterials [6]
**PHYS-1001-C: Non-Linear Physics (50 Lectures)**

**Preliminaries** [7]
Brief overview of non-linearities in physics, One-dimensional phase space, Flows, Fixed points and stability, Bifurcations – perfect and imperfect and their classification.

**Non-linear Dynamics** [28]
Two-dimensional phase space and phase portrait, Classification of fixed points and bifurcations in two-dimensions, Limit cycles, Closed orbits, Poincare-Bendixon theorem, Forced non-linear oscillators – van der Pol, Duffing, One-dimensional maps, Logistic map, period doubling,Lyapunov exponent, Lorenz map, Strange attractor, Chaos, Feigenbaum's theory, Interdisciplinary applications of non-linear dynamics.

**Non-linear waves** [7]
Solitons, KdV equation, Solutions and symmetries.

**Quantum Chaos** [8]
Quantum billiards, Random matrices – symmetries, universality classes, Gaussian ensembles, Spectral correlation

**PHYS-1001-D: Atomic and Subatomic Physics (50 Lectures)**

**Atomic and Molecular Physics** [20]
Fine structure of spectral lines; Selection rules; Lamb shift. Hyperfine interaction and isotope shift; Hyperfine splitting of spectral lines; selection rules, Many electron atoms: Equivalent and nonequivalent electrons; Energy levels and spectra; Hunds rule; Lande interval rule; Alkali spectra, Born- Oppenheimer approximation, Electronic states of diatomic molecules, 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: 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; 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, Group theory approach

**Nuclear Physics** [18]
Properties of nuclei, Nuclear models, 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., Beta decay, Selection rules, Double beta decay, Gamma decay, selection rules Nuclear reaction, Breit-Wigner dispersion relation, Nuclear fission.
Elementary Particle Physics

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, Brief introduction to Beyond the Standard Model Physics

PHYS-1091A: Condensed Matter Physics Lab

The Following Experiments are part of the lab

3. Determination of Hall Effect & Magnetoresistance of Polycrystalline Bismuth Sample at RT.
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 X-ray 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.
(Students will do 6-8 experiments among these)

PHYS-1091B: Astrophysics Lab

Data Analysis Projects
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

**PHYS-1092: Project-III**
Report and Viva 1

**PHYS-1093: Project-IV**
Presentation 2 and Viva 2

**PHYS-1094: Project-V**
Supervisor’s Assessment and Presentation 3