M.Sc (CBCS) Curriculum in Physics at Brahmananda Keshab Chandra College-2022

(This curriculum is same as that followed at West Bengal State University since July 2019)

The CBCS Curriculum to be followed consists of several Core Courses (both theory and lab) and Department Specific Elective Courses (DSE) together with AECC, GEC and SEC. For the DSE courses student has to take any one of the two courses offered.

Semester	Course Code	Course Title	Credit	Marks	Total
I	PHSPCOR01T	Mathematical Methods of Physics	4	50	Marks: 300 Credit: 22
	PHSPCOR02T	Classical Mechanics	4	50	
	PHSPCOR03T	Introductory Quantum Mechanics	4	50	
	PHSPCOR04T	Statistical Mechanics	4	50	
	PHSPCOR05P	General and Computational Lab I	4	50	
	PHSPAEC01M	Computational Ability Development	2	50	
II	PHSPCOR66T	Classical Theory of Fields & Electrodynamics	4	50	Marks: 300 Credit: 22
	PHSPCOR07T	Condensed Matter Physics	4	50	
	PHSPCOR08T	Applications of Quantum Mechanics	4	50	
	PHSPCOR09T	Nuclear and Particle Physics	4	50	
	PHSPCOR010P	General and Computational Lab II	4	50	
	PHSPSEC01M	Physics Problem Solving and Teaching Skill	2	50	
III	PHSPCOR11T	Advanced Statistical	4	50	Marks: 300 Credit: 24
	PHSPCOR12T	Advanced Quantum Mechanics	4	50	
	PHSPCOR13P	General and Computational Lab III	4	50	
	PHSPDSE01T	(a) Advanced Condensed Matter Physics I (b) Astrophysics I	4	50	
	PHSPCOR14M	Seminar and Colloquia	4	50	
	PHSPGEC01T	Elements of Modern Physics	4	50	
IV	PHSPCOR15M	Grand Viva	4	50	Marks: 300 Credit: 24
	PHSPDSE02T	(a) Quantum Field Theory (b) Non linear Dynamics	4	50	
	PHSPDSE03T	(a) Advanced Condensed Matter Physics II (b) Astrophysics II	4	50	
	PHSPDSE04P	(a) Advanced Condensed Matter Physics Lab (b) Astrophysics Lab	4	50	
	PHSPCOR16M	Project	8	100	

The detailed syllabus to be followed is the syllabus followed at West Bengal State University for the M.Sc in Physics programme.

West Bengal State University

PG Syllabus (CBCS)

(Effective from 2019-'20)

Programme: M.Sc. in Physics

Programme-specific outcome

The M.Sc. Programme in Physics trains a learner beyond the horizon of basic level Physics taught at the undergraduate level. Primary goal is to develop fundamental understanding in the core areas as well as specialized skill in the advanced areas of modern physics so as to enable the learner to actively participate in R&D programmes in Physics and related subjects at a professional level. Besides nurturing the reasearch potential of a learner, special emphasis is given in cultivating the teaching abilities also.

M.Sc. Syllabus (CBCS) in Physics
Draft outline proposed by the PGBoS

Semester-1

Sl. No.	Course Type	Course Title	Credit
1	Core 1.1 (Theory)	Mathematical Methods of Physics	4
2	Core 1.2 (Theory)	Classical Mechanics	4
3	Core 1.3 (Theory)	Introductory Quantum Mechanics	4
4	Core 1.4 (Theory)	Statistical Mechanics	4
5	Core 1.5 (Practical)	General and Computational Lab I	4
6	AECC	Computational Ability Development	2

Semester-2

Sl. No.	Course Type	Course Title	Credit
1	Core 2.1 (Theory)	Classical Theory of Fields & Electrodynamics	4
2	Core 2.2 (Theory)	Condensed Matter Physics	4
3	Core 2.3 (Theory)	Applications of Quantum Mechanics	4
3	Core 2.4 (Theory)	Nuclear and Particle Physics	4
4	Core 2.5 (Practical)	General and Computational Lab II	4
5	SEC	Physics Problem Solving and Teaching Skill	2

Semester-3

Sl. No.	Course Type	Course Title	Credit
1	Core 3.1 (Theory)	Spectroscopy and Statistical Physics	4
2	Core 3.2 (Theory)	Advanced Quantum Mechanics	4
3	Core 3.3 (Practical)	General and Computational Lab III	4
4	DSE 1 (Theory)	(a) Advanced Condensed Matter Physics I (b) Astrophysics I	4
5	DSE 2 (Project)	Seminar and Colloquia	4
6	GEC	Elements of Modern Physics	4

Semester-4

Sl. No.	Course Type	Course Title	Credit
1	Core 4.1 (Theory)	Grand Viva	4
2	DSE 3 (Theory)	(a) Quantum Field Theory (b) Non-linear Dynamics	4
3	DSE 4 (Theory)	(a) Advanced Condensed Matter Physics II (b) Astrophysics II	4
4	DSE 5 (Practical)	(a) Condensed Matter Physics Lab (b) Astrophysics Lab	4
5	Core 4.2 (Project)	Project	8

Semester I

Core 1.1 : Mathematical Methods for Physics 60 Lectures

Course Outcome : Every branch of physics depends heavily on mathematical methods. Objective of this course is to enable to students (i) to understand and apply the concept of discrete groups; (ii) to understand and apply techniques of solving of second order linear ordinary differential equation; (iii) to understand and apply the theory of functions of complex variable and to perform contour integration; (iv) to understand various properties of special functions to be applied in most of the following courses of this program.

1. Group Theory: Definition of a group; Multiplication table; Rearrangement theorem; Subgroups and cosets; Conjugacy Classes; elements, class and factor groups; Class multiplication; Isomorphism and homomorphism; Illustrations with point symmetry groups. **10L**

2. Differential Equations occurring in Physics: Theory of second order linear homogeneous differential equations; Singular points - regular and irregular singular points; Frobenius method; Fuch's theorem; Linear independence of solutions - Wronskian, second solution. Sturm-Liouville theory; Hermitian operators; Completeness; Inhomogeneous differential equations - Green's functions. **20L**

3. Complex variable theory: Complex numbers, triangular inequalities, Schwarz inequality; Function of a complex variable - single and multiple-valued function, limit and continuity; Differentiation - Cauchy-Riemann equations and their applications; Analytic and harmonic function; Complex integrals, Cauchy's theorem (elementary proof only), converse of Cauchy's theorem, Cauchy’s Integral Formula and its corollaries; Series – Taylor and Laurent expansion; Classification of singularities; Branch point and branch cut; Residue theorem and evaluation of some typical real integrals using this theorem. Idea of analytic continuation – definition and some elementary theorems; Schwarz reflection principle, power series method of analytic continuation. **20L**

4. Special Functions: Basic properties (recurrence and orthogonality relations, series expansion and generating function) of Bessel, Legendre, Hermite and Laguerre functions. **10L**

Recommended Books:

1. Mathematical Methods for Physics and Engineering: A Comprehensive Guide 3rd Edition, K. F. Riley, M. P. Hobson, S. J. Bence, Cambridge
2. Mathematical Methods for Physicists: A Comprehensive Guide 7th Edition. G. B. Arfken, H. J. Weber, Frank E. Harris, Academic Press
3. Applied Mathematics for Engineers and Physicists, L. A, Pipes, L. R. Harvill
4. Elements of Group Theory for Physicists, 3rd ed., A. W. Joshi, Wiley
5. Group Theory and Quantum Mechanics, 3rd ed., M. Tinkham, Dover
6. Mathematics for Physicists, Denney and Krzywicki, Dover

Core 1.2 : Classical Mechanics 60 Lectures

Course outcome: To enable the student to grasp the fundamental principles of Mechanics and to apply those principles in different branches of Physics. Further, to learn the alternate formulations of Mechanics which can be applied beyond the regime of Classical Physics, namely, the Variational principle and Action formalism, Lagrangian and Hamiltonian formulation etc.

1. Symmetries and Conservation. Rotation- 2 dimensional (Angular momentum and Torque); Generalization- 3 dimensional (Angular momentum vector, inertia tensor, Euler’s equation, gyroscope), Accelerated frame of reference (Foucault's pendulum, tides), Central force motion; Kepler’s laws. **11L**

2. Rigid bodies: Independent coordinates, orthogonal transformations and rotations (finite and infinitesimal), Euler's theorem, Euler angles, Inertia tensor and principal axis system, Euler's equations, Heavy symmetrical top with precession and nutation. **10L**

3. Lagrangian formalism: Stationarity of Action as the basic law of Physics, applications of Lagrange's equation: velocity dependent potential; symmetry and conservation principles; small oscillations, normal modes and frequencies, the heavy symmetric top. **11L**

4. Hamiltonian formalism: Calculus of variations; Hamilton's principle; Lagrange's equation from Hamilton's principle; Legendre transformation and Hamilton's canonical equations; Canonical equations from a variational principle; Principle of least action. **8L**

5. Canonical transformations and the concept of integrability; Generating functions, examples of canonical transformations, group property, Integral variants of Poincare, Lagrange and Poisson brackets, Infinitesimal canonical transformations, Conservation theorem in Poisson bracket formalism, Jacobi's identity, Angular momentum Poisson bracket relations. **9L**

6. Hamilton Jacobi theory: The Hamilton-Jacobi equation for Hamilton's principle function; The harmonic oscillator problem; Hamilton's characteristic function; Action angle variables. **8L**

7. Classical chaos: Periodic motion; Perturbations and Kolmogorov-Arnold-Moser Theorem; Attractos; Chaotic trajectories and Liapunov exponents; Poincaré maps. **3L**

Recommended Books:

1. Mechanics, L.D. Landau & E.M. Lifshitz (Volume 1 of A Course of Theoretical Physics), Pergamon Press.
2. Classical Mechanics, N.C. Rana and P.S. Joge, Tata-McGraw-Hill Education.
3. Classical Mechanics, 3rd ed., Herbert Goldstein, Pearson Education.
4. Mechanics, 3rd ed., Keith R. Symon, Pearson.
5. Classical Mechanics: A Course of Lectures, A. K. Raychaudhuri; OUP India

Core 1.3 : Introductory Quantum Mechanics 60 Lectures

Course Prerequisite: Basic understanding in early quantum theory, wave function. Schrödinger equation-solution of bound state problems in 1D.

Course Outcome: Students will know and understand the concept of vector space and will be able to apply immediately in formulation of Quantum Mechanics (this can also find application in many other fields of quantitative science). Students will be exposed to the postulatory approach of quantum mechanics. Students will be able to deal with the angular momentum operator and its wave-function. Students will be able to solve bound state problems in three dimension in central field potential. Students will be able solve problems in stationary and time dependent perturbation techniques.

1. Mathematical preliminaries: Vector space, subspace, linear independedinger nce, dimension, inner product, norm, metric, Hilbert space, Linear Operators, Eigen values and Eigen vectors, hermiticy, commutation and simultaneous eigenstates, complete set. **14L**

2. Basics of Quantum mechanics: States of a system as Vectors and dynamical variables as operators, Canonical commutation relations, coordinate and momentum representations, time development in Schrödinger and Heisenberg pictures, the uncertainty relations. **6L**

3. One dimensional linear Harmonic Oscillator using raising and lowering operator. **2L**

4. Rotation and Angular Momentum in Quantum Mechanics: Orbital Angular Momentum, Angular Momentum as generator of infinitesimal rotaions. Raising and Lowering operators, Matrix representation of the angular momentum operator, Clebsch-Gordan Coefficients. **12L**

5. Bound State Central Field problems in three dimensions. **10L**

6. Approximate methods for stationery states: Time-independent perturbation: Non degenerate and degenerate perturbation. **8L**

7. Approximate methods for time dependent problems: Solvable two level system, time dependent perturbation theory, interaction picture the adiabatic and sudden approximations. **8L**

Recommended Books:

1. Elements of Quantum Mechanics, B. Dutta Roy, New Age
2. Quantum Mechanics: Concepts and Applications, N. Zettili, John Wiley
3. Quantum Mechanics (Schaum's outline series), 2^{nd} ed., Peleg, Pnini, Zaarur and Hecht, McGraw-Hill
4. Quantum Mechanicsy, C. Cohen-Tannoudji, B. Diu, F. Laloe, Wiley VCH
5. Quantum Mechanics, L. Schiff, McGraw-Hill
6. Vector Spaces and matrices, R.M. Thrall, L. Tornheim, Dover
7. Introduction to Matrices and Linear Transformation, D.T. Finkbeiner, Courier Corporation
8. Introduction to Quantum Mechanics, 2^{nd} ed., D.J. Gritffith, Pearson

Core 1.4 : Statistical Mechanics 60 Lectures

Course outcome: To enable the student to grasp the fundamental principles of Statistical Mechanics and to apply those principles in solving various problems related to different branches of Physics. Also to develop the ability to formulate and solve problems involving many degrees of freedom that draw recent research interest in the area of Statistical Mechanics.

1. Fundamentals and microcanonical systems: Objective of statistical mechanics; Method of statistical mechanics, macrostates, microstates, probability, ensemble, postulate of equal a priori probability (PEAP). $S=k\ln\Omega$ relation for a microcanonical system. Application to Ideal Gas. Entropy of ideal gas mixture, Gibbs' Paradox. **6L**

2. Interactions between two systems - thermal, mechanical and diffusive: Thermal interaction-concept of temperature and entropy,, heat, second law of thermodynamics for a classical ideal gas; Nature of P(E) distribution in equilibrium after thermal interaction; Mechanical interaction-generalized force; First law and equation of state for an isolated system; Diffusive interaction-chemical potential. **6L**

3. Canonical systems: Partition function; Equation of State; Energy fluctuation and C_v; Microcanonical and canonical distribution using Lagrange's undetermined multiplier; Applications in a two level system, a system of harmonic oscillators, paramagnetic gas. **8L**

4. Grand canonical system: Partition function; Equation of state; Fluctuation in the number of particles; $PV=kT \ln Z$ relation. Application to ideal gas. **4L**

5. Classical non-ideal gas: Mean field theory and Van der Wall's equation of state; Cluster integrals and Mayer-Ursell expansion. **8L**

6. Quantum statistical mechanics: Density Matrix; Quantum Liouville theorem; Density matrices for microcanonical, canonical and grand canonical systems; Simple examples of density matrices-one electron in a magnetic field, particle in a box; Indistinguishable particles: B-E and F-D distributions. **8L**

7. Ideal Bose and Fermi gas: Equation of state of Bose gas; Bose condensation; Equation of state of ideal Fermi gas; Fermi gas at finite T. Low temperature specific heat of elecron gas. **10L**

8. Special topics: Ising model-partition function for one dimensional case; Chemical equilibrium and Saha ionisation formula. Phase transitions-first order and continuous, order parameter, response functions and fluctuation dissipation theorem, critical indices, Scaling relations, correlation length and idea of a diverging correlation length. Calculation of exponents from Landau's theory, upper critical dimension. **10L**

Recommended Books:

1. Statistical Mechanics, 2nd ed., R. K. Pathria, Butterworth Heinmann
2. Thermodynamics and Statistical Mechanics, W. Greiner, L. Neise and H. Stocker, Springer
3. Statistical Mechanics, 2nd ed., K. Huang, John Wiley
4. An Introductory Course of Statistical Mechanics, Palsh B. Pal, Narosa
5. Equilibrium Statistical Physics, 3rd ed., M. Plischke and B. Begersen, World Scientific

Core 1.5 : General and Computational Lab I 120 Class Hours

Unit I : General Lab I

Course Outcome: Student gets trained i) in performing experiments and recording data on reasonably state of the art equipment, ii) in analyzing data to draw the final conclusions. The experiments are so chosen so as to give them maximum exposure to fascinating field of experimental physics based on the theoretical knowledge acquired by the student. To encourage students in critically reviewing the results, experimental set-up and procedure, rather than merely performing standard experiments.

List of experiments:

1) Determination of Hall coefficient of p and/or n type semiconductor
2) Frank-Hertz experiment
3) Determination of e/m of electron
4) Determination of Dielectric Constant of a non-polar organic liquid
5) Transfer Characteristic of Enhancement type MOSFET
6) Computer interfacing using PHOENIX kit developed by UGC IUAC, New Delhi

* Some more experiments may be introduced as and when available.

Unit II : Computational Physics Lab I

Course Outcome: Since familiarity at the fundamental level with the logical structure and grammar and syntax of any computer language can enable the student to quickly change, if necessary, to any other, we shall generally concentrate on one such language. Target is to inculcate the ability to write programs by the students themselves for understanding different concepts and solving different problems of physics. Each year problem sets need to be different.

► Language to be used for learning the following basic principles is Python

Students has to develop programs:

1) To evaluate special functions and to study their behaviours
2) To construct the histogram from a data file and to calculate different moments
3) To Generate data according a given equation, adding noise and extracting parameters using linear and nonlinear (Levenberg Marquardt) least square method
4) To implement Discrete Fourier transform

Recommended Books:

1. Computational Physics: Problem Solving with Python, 3rd Edition Rubin H. Landau, Manuel J Páez, Cristian C. Bordeianu
2. Introduction to Python for Science and Engineering (Series in Computational Physics), David J. Pine, CRC Press

AECC : Computational Ability Development 30 Class Hours

Course Outcome: To develope the ability of computer programming. Since Python is one of the most widely used language in academics and industry, a good programming skill in python will enhance the employability of the students in different research labs, IT sector and also in the field of educational content development.

► Language to be used for learning the following basic principles is Python

Constants and Variables, Controls, std I/O, data structures like list, tuple, string, directory, set, user defined functions, functions with default arguments, functions with arbitrary arguments. Lamda function, list comprehension, Class, methods (with self and also with self-other), instantiation, inheritance, operator overruling, Numpy, Scipy, Matplotlib and Sympy.

Recommended Books:

1. Python Crash Course , Eric Matthes , No Starch

2. Python for beginners. https://stackoverflow.com/questions/18754276/python-for-beginners

Semester II

Core 2.1 : Classical theory of Fields and Electrodynamics 60 Lectures

Course outcome: To familiarize the learner with the techniques of field theoretic study that forms the core of many advanced topics in Physics, e.g., Quantum field theory, Nuclear Physics, Condensed Matter Physics, General Relativity and so on. The student should be able to understand and apply the concepts of Electrodynamics. The student should develop an understanding of the basics of electromagnetic (EM) radiation and relativistic nature of EM-field.

1. Principles of Galilean relativity and Special Relativity, Notion of space-time interval, simultaneity and coincidence, Transformation of coordinates and velocities,Tensors as geometrical objects. **8L**

2. Dynamics of a relativistic free particle through action principle and symmetries, Interaction of a charged particle with a four-vector field, identification of electromagnetic field tensor and its gauge symmetry and conservation law, Lorentz-force equation. **10L**

3. Generalization of particle mechanics to field theory and field theoretic action for a scalar field; Dynamics of a four-vector field and Maxwell's field equations. **4L**

4. Noether theorem and Symmetries, Space-time symmetries of Real scalar field, Global and Local Gauge symmetries of Complex scalar field and introduction of gauge field to restore local gauge symmetry, Covariant derivative. **8L**

[**Note:** In items 1-4 above, everything has to be done in covariant notation demonstrating their connection to the three-vector notation.]

5. Wave equations for vector and scalar potential and solution, Retarded potential and Lienard-Wiechert potential, Electric and Magnetic fields due to uniformly moving charges and an accelerated charge, Linear and circular acceleration and angular distribution of power radiated, Bremsstrahlung, Synchrotron and Cerenkov radiation, Reaction force of radiation. **30L**

Recommended Books:

1. Classical Theory of Fields, L.D. Landau & E.M. Lifshitz (Volume 2 of A Course of Theoretical Physics) Pergamon Press.
2. Gravitation: Foundations and Frontiers, 1st ed., Thant Padmanabhan, Cambridge University Press.
3. Introduction to Electrodynamics, 3rd ed., David J.Griffths, Prentice-Hall of India.
4. Classical Electrodynamics, 3rd ed., J.D.Jackson, Wiley
5. Classical Electromagnetic Radiation, 3rd ed., M. A. Heald and J. B. Marion, Saunders College Publishing .

Core 2.2 : Condensed Matter Physics 60 Lectures

Course outcome: To familiarize the learner with the basic facts and underlying principles that form the back-bone of Condensed Matter Physics. To develope the skill of formulating and systematically solving problems in Condensed Matter Physics that will find applications in Material Physics as well as in other related branches of Physics.

1. Chemical Bonding in solids: Covalent, molecular and ionic bonding, metallic bonding, The hydrogen bond, the noble gases; Lennard-Jones potential, Cohesive energy and bulk modulus of the solid noble gases and alkali halides, Madelung constant. **5L**

2. Structure of solid matter: Crystal structure- Bravais lattice and primitive vectors, Conventional unit cell, primitive unit cell and Wigner-Seitz cell, point symmetry, 32 crystal classes (Point groups), concept of basis and space group; simple crystal structures, lattice planes and Miller indices, Reciprocal lattice and Brillouin zone, Bragg's interpretation of Laue condition, structure factor, x-ray diffraction- Laue, Rotating crystal, powder, electron and neutron diffraction by crystals, Surface crystallography. **7L**

3. Free electron in Solids: Drude theory of metals – basic assumption, free electron gas in an infinite square-well potential, Fermi gas at T=0 K, Fermi-Dirac Statistics, Density of allowed wave vectors, Fermi momentum, energy and Temperature, ground state energy and bulk modulus, specific heat capacity of electrons in metals. **6L**

4. Electronic band structure of solids: Failures of free electron theory, Periodic potential and Bloch’s theorem; Band theory – nearly free electrons, band gap, number of states in a band; tight binding approximation; other methods of calculating band structures; semi-classical dynamics of electrons in a band; Landau levels - de Haas van Alphen effect. **10L**

5. Semiconductors: General properties and examples of semiconductors, effective mass- cyclotron resonance, charge carrier density in intrinsic semiconductors – statistics, Doping, carrier density in doped semiconductors – statistics, impurity band conduction, p-n junction, metal-semiconductor Schottky contact, Important semiconductor devices, heterostructures and superlattices. **5L**

6. Dynamics of atoms in a crystal: Failures of the static model, Classical theory of lattice vibration under harmonic approximation, the monoatomic and diatomic linear lattices, acoustical and optical modes, long wavelength limits, Adiabatic approximations, Quantum theory of the harmonic crystal- normal modes and phonons, phonon statistics, high and low temperature specific heat, Models of Debye and Einstein, comparison with electronic specific heat, effects due to anharmonocity – thermal expansion and heat conduction by phonons. **6L**

7. Magnetism : Origin, diamagnetism and paramagnetism, crystal field splitting, Hund's rule, Van-Vleck paramagnetism, Pauli paramagnetism, Nuclear magnetic resonance – probe for magnetic structures, ESR, exchange interaction – electrostatic origin of magnetic interactions, magnetic interactions in the free electron gas, Heisenberg model, Ferromagnetism, ferromagnetic domains, ferri and antiferromagnetism, Mean field theory- success and failure, Dipolar interactions. **8L**

8. Superconductivity: Phenomenological description – critical temperature, persistent current, Meissner effect; Thermodynamics of superconducting transition; The two-fluid model; London equation; Type I and II superconductors; the BCS ground state (qualitatuive idea of phonon mediated pairing), Quantization of magnetic flux and Josephson effect, high T_C superconductor (informative only). **7L**

9. Dielectric properties of materials: Dielectric function, orientational polarizability, Classical theory of electronic and ionic polarization, optical absorption, Piezoelectricity, Spectroscopy with electrons and phonons, Optical properties of ionic crystals in infrared regime. **6L**

Recommended Books:

1. Elementary Solid State Physics, M. Ali Omar, Pearson
2. Introduction to Solid State Physics, 8th ed., C. Kittel, Wiley
3. Solid State Physics, N. Ashcroft and N.D. Mermin, Saunders College
4. Principles of the Theory of Solids, 2nd ed., J. M. Ziman, Cambridge
5. Solid-State Physics, 4th ed., H. Ibach and H. Luth, Springer
6. Oxford Master Series in Condensed Matter Physics (Oxford)
7. Physics of Semiconductor Devices, 3rd. ed., S. M. Sze and K. K. Ng, Wiley
8. Electrionic Properties of Materials, 3rd ed., R. E. Hummel, Springer
9. Introduction to Superconductivity, 2nd ed., A. C. Rpse-Innes and E. H. Rhoderick, Pergamon Press

Core 2.3 : Applications of Quantum Mechanics 60 Lectures

Course Outcome: The objective of this course is to enable the students (i) to apply quantum mechanics in studying atomic physics of increasing complexities; (ii) to learn WKB approximation, an important tool to be applied in many application of atomic, molecular and nuclear physics; (iii) to learn the techniques of scattering problems in quantum mechanics: to be applied in various branches of modern nuclear and subatomic physics.

1. Hydrogen Spectrum: Review of basic concepts – hydrogenic atom in an em field – transition rates – absorption – stimulated emission ; the dipole approximation; Selection rules for one electron atom – magnetic dipole and electric quadrupole transition ; line shapes and width – pressure and Doppler broadening. **8L**

2. Relativistic correction terms for an one electron atom – fine structure of hydrogenic atoms, hyperfine interactions- hyperfine structure – magnetic dipolar and quadrupolar hyperfine splitting – isotope shift. **8L**

3. Atoms in electric and Magnetic field **-** Normal and anomalous Zeeman effect ; Paschen **-**Back effect ; Stark effect ; **6L**

4. Helium atom **-** Central field approximation**-** the Thomas Fermi model – spin**-**Pauli exclusion princi central field approximation**-** the Thomas Fermi model – spin-Pauli exclusion principle – Ground sate and first excited state. **4L**

5. Many electron atoms –Slater determinant – electron states in a central field – degeneracies – periodic system of elements; correction to the central field approximation – L-S coupling – possible terms; Hund's rules – multiplet splitting and the Lande interval rule; j-j coupling; Zeeman effect in a many electron atom. **4L**

6. The quantum theory of scattering: the green's function, the Born approximation, the Lippman-Schwinger formalism, the partial wave approach, phase shifts, scattering length, resonances, the Eikonel approximation. **20L**

7. Approximate methods for stationery states: WKB approximation. **10L**

Books Recommended:

1. Elements of Quantum Mechanics, B. Dutta Roy, New Age
2. Quantum Mechanics: Concepts and Applications, N. Zettili, Wiley
3. Quantum Mechanics (Schaum's outline series), 2^{nd} ed., Peleg, Pnini, Zaarur and Hecht, McGraw-Hill
4. Quantum Mechanicsy, C. Cohen-Tannoudji, B. Diu, F. Laloe, Wiley VCH
5. Quantum Mechanics, L. Schiff, McGrow-Hills
6. Introduction to Quantum Mechanics, D.J. Gritffith, D.F. Scröfter, Cambridge University Press
7. Physics of Atoms and Molecules, 2nd Edition , B.H. Brandsden C. J. Joachain, Pearsonon

Core 2.4 : Nuclear and Particle Physics 60 Lectures

Course Outcome: To familiarize the student with the basic facts and experiments of Nuclear Physics. To demonstrate how the basic principles of physics are applied to the understanding of the properties of the atomic nucleus and nuclear reactions. To introduce the student with the basic phenomenology in particle physics. To promote student's interest in the area of high energy physics.

1. Nuclear properties: Basic nuclear properties – Nuclear size, Rutherford scattering, Determination of nuclear radius and charge distribution, mass and potential radius, nuclear form factor, mass and binding energy, Angular momentum, parity and symmetry, Magnetic dipole moment and electric quadrupole moment. X-ray isomer shift, Neutron Proton Separation Energy. **4L**

2. Two-body bound state: Properties of deuteron, Schrodinger equation and its solution for ground state of deuteron, rms radius, spin dependence of nuclear forces, electromagnetic moment and magnetic dipole moment of deuteron and the necessity of tensor forces. **4L**

3. Two-body scattering: Experimental *n-p* scattering data, Partial wave analysis and phase shifts, scattering length, magnitude of scattering length and strength of scattering, significance of the sign of scattering length; Scattering from molecular hydrogen and determination of singlet and triplet scattering lengths, effective range theory, low energy p-p scattering, Nature of nuclear forces: charge independence, charge symmetry and isospin invariance of nuclear forces. **6L**

4. Nuclear structure: Liquid drop model, Bethe-Weizsacker binding energy/ mass formula, Fermi gas model, Shell model (Extreme Single particle, Single particle, and Independent Particle Shell Models), Collective model. **7L**

5. Nuclear reactions and Fission: Different types of reactions, Quantum mechanical theory, Resonance scattering and reactions --- Breit-Wigner dispersion relation; Compound nucleus formation and break-up, Statistical theory of nuclear reactions and evaporation probability, Optical model; Principle of detailed balance, Transfer reactions, Nuclear fission: Experimental features, spontaneous fission, liquid drop model, barrier penetration, statistical model. Elementary ideas about astrophysical reactions, Nucleosynthesis and abundance of elements. **10L**

6. β-decay and weak interaction: Energetics of various β decays, *V-A* theory of allowed β decay, Selection rules for Fermi and Gamow-Teller transitions, Parity non-conservation and Wu's experiment, Goldhaber's experiment; Elementary ideas about the gauge theory of weak interaction. The problem of mass generation and the need for the Higgs mechanism. Pion decay. **8L**

7. Semi-quantitative discussions on Alpha, Beta, and Gamma Decays. **3L**

8. Experiemnatl Techniques in Nuclear physics. Interactions of Heavy charged particles and matter during their passage through materials. **6L**

9. Strong interaction: Symmetries and conservation laws, Hadron classification by isospin and hypercharge, SU(3) algebra; Young tableaux rules for SU(3); Quarks; Colour; Gell-Mann – Okubo

mass relation. Magnetic moment of hadrons. **7L**

10. Electroweak theory: Elementary ideas of electroweak unification and Standard Model. **2L**

11. Big bang nucleo-synthesis
Qualitative idea of BBN, relative abundances of hydrogen, helium, and deuterium. **3L**

Recommended Books:

1. Nuclear Physics: Principles and Applications, J.S. Lilley, John Wiley
2. Theory of Nuclear Structure, M.K. Pal, Levant
3. Nuclear Physics: Theory and Experiments, R.R. Roy and B.P. Nigam, John Wiley
4. Atomic and Nuclear Physics (Vol. 2), S.N. Ghoshal, S. Chand
5. Introduction to High Energy Physics, 4th ed., D.H. Perkins, Cambridge Univ. Press
6. Introduction to Elementary Particles, 2nd ed., D. J Griffiths, JohnWiley
7. Nuclear and Particle Physics, W.E. Burcham and M. Jobes, Longman
8. Introductory Nuclear Physics, K. S. Krane, John Wiley
9. Introduction to Nuclear and Particle Physics, Das & Ferbel, World Scientific

Core 2.5 : General and Computational Lab II **120 Class Hours**

Unit I : General Lab II

Course Outcome: To introduce experiments in modern physics which are related to the domain of theoretical knowledge of the student. To give exposure to techniques of determination of fundamental constants and basic measurement techniques in modern physics. Emphasis to be given on critically reviewing the results, experimental set-up and procedure, rather than merely performing standard experiments. Student is to be encouraged to think of alternative experimental design of their own.

1. Band gap measurement in a semiconductor using Four Probe method
2. Determination of Ferromagnetic-Paramagnetic transition temperature of Ferrite
3. Study of dispersion relation of elastic waves in monatomic and diatomic lattices by using electrical analogue circuits.
4. Verification of Wiedemann Frantz Law in metals
5. Determination of e/m electron by magnetic focusing method
6. Determination of Planck's constant sing a LED
7. Particle size estimation using diffraction
8. Computer interfacing using PHOENIX kit developed by UGC IUAC, New Delhi

* Some more experiments may be introduced as and when available.

Unit II : Computational Lab II

Course Outcome: A good knowledge in numerical methods and the skill to implement them in program code is necessary for computational physics. Students will be able (i) to develope codes for a given numerical method; (ii) to compare the efficiency of different alternative methods; (iii) to use the python scipy and numpy numerical library for numerical calculation.

Implementation of Numerical methods both from the basic algorithms and using scipy :
1. Gaussian Elimination with partial pivoting and Gauss Jordon elimination, Determinant.
2. Solving linear system of equations, determinant, inverse of a matrix.
3. Root searching of algebraic equation (1D and Multidimensional),
4. Integration.
5. Ordinary Differential equation (1 D and Multidimensional) interpolation.
6. Matrix diagonalization.

Recommended Books:

1. Numerical Recipes: The Art of Scientific Computing, 3rd ed., William H. Press, Saul A. Teukolsky, William T. Vetterling and Brian P. Flannery, Cambridge
2. Computational Physics: Problem Solving with Python, 3rd ed., Rubin H. Landau, Manuel J Páez, Cristian, C. Bordeianu
3. Introduction to Python for Science and Engineering (Series in Computational Physics), David J. Pine, CRC Press

SEC : Problem Solving and Teaching Skills 30 Class Hours

Course outcome: To develop skill of solving innovative problems in core areas of Physics as well as problems of inter-disciplinary nature. To train the learner develop teaching skill in Physics. The course intends to help the learner specifically prepare for taking up a professional career in Physics.

Unit 1: Problem Solving Skill 15 hours

Training of specific skills for solving advanced problems in General Physics covreing core courses learnt at the UG level and PG level (1^{st} and 2^{nd} semesters). Standard problems as well as innovative real life problems and techniques of solving them using analytical, graphical and/ or numerical methods. Problems are to be selected from:

(i) Newtonian, Lagrangian and Hamiltonian dynamics; non linear dynamics.

(ii) Electrostatics; Magnetostatics; Maxwell's equations; Special Theory of Relativity.

(iii) Laws of thermodynamics: applications; equilibrium statistical mechanics– classical and quantum statistics; application to elementary problems in astrophysics and condensed matter physics.

(iv) Early quantum theory; non-relativistic quantum mechanics of simple systems: eigenvalue and eigenfunction calculation in bound state problems; applications; application of approximate methods like WKB, Perturbation theories, Variational techniques; applications of scattering theories.

(v) Graph drawing; real analysis; constrained maximization; calculus of variation; complex analysis; differential equations; special functions in mathematical physics; integral transforms; vector analysis and linear algebra; numerical solution of algebraic equations; curve fitting; error analysis.

(vi) X-ray diffraction and crystal structure of solids; free electron theory of metals; energy bands in solids; electrical and optical properties of solids; magnetism; superconductivity.

(vii) Phenomenology of nuclear structure; liquid drop and shell models of nuclei; nuclear reactions.

Note: *Emphasis is to be given on application of basic theory/ formulae to given problems rather than memorizing them.*

Unit 2: Teaching Skill 15 hours

Micro-teaching by students on topics selected from the following broad areas:

(i) Classical Mechanics

(ii) Classical Electromanetism

(iii) Thermodynamics and Statistical Mechanics

(iv) Modern Physics including Quantum Theory

(v) Mathematical Methods of Physics

Books Recommended:

1. Classical Mechanics, 3rd ed., T. W. B. Kibble, Longman
2. Classical Mechanics, 3rd ed., H. Goldstein, C. Poole, J. Safko, Addison-Wesley
3. Classical Dynamics of Particles and Systems, 5th ed., S. T. Thornton and J. B. Marion, Thomson
4. Introduction to Electrodynamics, 4th ed., D. J. Grifftths, Pearson
5. Classical Electromagnetic Radiation, 3rd ed., M. A. Heald and J. B. Marion, Saunders College
6. An Introductory Course of Statistical Mechanics, Palsh B. Pal, Narosa
7. Statistical Mechanics, 2nd ed., R. K. Pathria, Butterworth Heinmann
8. Introduction to Quantum Mechanics, 2nd ed., D. J. Griffiths, Pearson
9. Physics of Atoms and Molecules, B. H. Bransden and C. J. Joachain, Pearson
10. Mathematical Methods for Physics and Engineering, 2nd ed., K. F. Riley, M. P. Hobson and S. J. Bence, Cambridge Univ. Press
11. Numerical Mathematical Analysis, 6th ed., J. B. Scarborough, Oxford Univ. Press
12. Elementary Solid State Physics, M. Ali Omar, Pearson
13. Introduction to Solid State Physics, 8th ed., C. Kittel, John Wiley
14. Introductory Nuclear Physics, K. S. Krane, John Wiley
15. Nuclear Physics, 2nd ed., I. Kaplan, Addison-Wesley
16. Schaum's Outlines Complex Analysis, 2nd ed., M. R. Spiegel et. al., McGraw Hill
17. Schaum's Outlines Vector Analysis, M. R. Spiegel, McGraw Hill
18. Schaum's Outlines Theoretical Mechanics, M. R. Spiegel, McGraw Hill
19. Problems in Electrodynamics, 2nd ed., V. V. Batygin and I. N. Toptygin, Academic Press
20. Problems in Qunatum Mechanics, F. Constantinescu and Magiyari, Pergamon Press
21. Solid State Physics Problems and Solutions, L. Mihaly and M. C. Martin, John Wiley
22. Princeton Problems in Physics with Solutions, N. Newbury et. al., Princeton Univ. Press
23. University of California, Berkeley Physics Problems with Solutions, Min Chen, Prentice-Hall India

Semester III

Core 3.1 : Advanced Statistical Mechanics and Molecular Spectroscopy
60 Lectures

Unit 1 : Advanced Statistical Mechanics **30 Lectures**

Course outcome: To take the student beyond the scope of equilibrium statistical mechanics and introduce the basic elements of non-equilibrium statistical mechanics. To introduce the modern theory of phase transition.

1. Brief introduction to thermodynamics and equilibrium statistical mechanics, Basic postulates: Ergodic hypothesis, Boltzmann hypothesis, equal weights hypothesis. Introduction to Non-equilibrium phenomenon. Concepts of Equilibrium and Steady State Processes-Liouville Theorem. **4L**

2. Transport Properties using elementary Kinetic Theory **4L**

3. Transport Properties using Boltzmann transport equation using Path Integral Formalism and Relaxation time approximation of collision. **4L**

4. Transport properties by considering Actual Collision integral and Boltzmann Transport Equations. Collisions from Fixed Scatter and Binary Collisions. 5**L**

5. Langevin equation, Fokker Planck equation. **5L**

6. Phase transitions. Landau theory and elements of scaling and renormalization group. **8L**

Recommended Books:

1. Fundamentals of Statistical and Thermal Physics, F. Reif, McGraw-Hill

2. Statistical Mechanics, K. Huang, 2^{nd} ed., Wiley

3. Equilibrium Statistical Physics, 3^{rd} ed., M. Plischke and B. Begersen, World Scientific

4. Statistical Physics: Equilibrium and Non Equilibrium Aspects, J. K. Bhattacharjee, Allied

5. Statistical Physics (Course of Theoretical Physics-Vol.5), L. D. Landau and E. M. Lifshitz, Pergamon Press

6. Statistical Mechanics, 2^{nd} ed., R. K. Pathria, Butterworth Heinmann

7. Statistical Mechanics, S. K. Ma, World Scientific

Unit 2 : Molecular spectroscopy 30 Lectures

Course outcome : The student at the end of the course should be able to (i) explain the principle and instrumentation of microwave, vibration-rotation Raman and infra-red spectroscopy and interpret microwave, vibration-rotation Raman and infra-red spectra for chemical analysis, and (ii) explain the principle and instrumentation of electronic spectroscopy and analyze the electronic spectra of different species.

1. Fundamentals of spectroscopy: transition rates – absorption, stimulated emission and spontaneous emission ; the electric dipole approximation and associated selection rules for transition; Selection rules for one electron atom – magnetic dipole and electric quadrupole transition; Einstein's relations, line shapes and width – pressure and Doppler broadening. **8L**

2.Basics of Molecular Spectroscopy: Born-Oppenheimer approximation –Decoupling of electronic and nuclear degrees of freedom, Rigid rotator model for diatomic molecule, decoupling of rotational and vibrational degrees of freedom. **4L**

3. Microwave spectroscopy: Rotation and moment of Inertia of different types of molecules, Rotational spectrum of rigid diatomic molecule – Selection rules – intensities, effect of isotropic substitution, rot spectrum of non-rigid rotor ; rot spectrum of polyatomic molecules. **6L**

4. Vibrational spectroscopy: Simple harmonic oscillator model of vibrating diatomic molecule; selection rule and spectrum, anharmonic effects; vibration – rotation spectrum of a diatomic molecule– breakdown of Born-Oppenheimer approximation ; Effect of rotation on the spectrum of a vibrating polyatomic molecule; quantum and classical theory of molecular polarizability – polarizability ellipsoid- Raman active and inactive modes; Raman effect – Stokes and anti-Stokes lines – rule of mutual exclusion and application. **8L**

5. Electronic spectroscopy of molecules: electronic spectrum – intensity of vibrational – electronic spectrum; Franck-Condon principle – rotational fine structure – Fortrat diagram. **4L**

Books Recommended:

1. Fundamentals of molecular spectroscopy, 4th ed., Colin Banwell and Mc Cash, TMH publishers.
2. Molecular structure and Spectroscopy, G.Aruldhas, Prentice Hall of India.
3. Atomic and Molecular Spectroscopy : basic aspects and practical applications, 3rd ed., Sune Svanbag, Springer.
4. Molecular Spectroscopy, Jeanne L Mc Hale, Pearson Education

Core 3.2 : Advanced Quantum Mechanics 60 Lectures

Course outcome: To impress upon the learners how symmetry and group theory works in sub-atomic world and how Lorentz symmetry restricts and thereby ensures the very structure of relativistic quantum mechanics. Also to demonstrate the real necessity of an action principle in the quantum domain through the introduction of path-integral techniques. To familiarize the learner with the basic facts and underlying principles that work in the relativistic regime of a sub-atomic world.

1. Symmetries in Quantum mechanics: Symmetries, Conservation laws, and Degeneracies, Discrete symmetries-Parity, Space Inversion, and Time reversal. **8L**

2. Group theory in Quantum mechanics: Definitions; Group representations-faithful and unfaithful representations, reducible and irreducible representations; Schur's lemma; The great orthogonality theorem; Lie groups and Lie algebra, product representation of SU(2) and relation with angular momentum. **12L**

3. Introduction to Path-integrals: The Propagation amplitude for a non-relativistic single particle, Transitivity property of the propagation amplitude and its connection to the position and momentum basis in non relativistic quantum mechanics, Time-slicing and connection of path-integral quantization with Hamiltonian formulation of non-relativistic quantum mechanics. **20L**

4. Relativistic quantum mechanics: Klein-Gordon equation, interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Relativistic Hydrogen atom, Spin and magnetic moment of the electron; Non-relativistic reduction; Helicity and chirality; Properties of gamma matrices; Charge conjugation; Normalisation and completeness of spinors; Lorentz covariance of Dirac equation. **20L**

Books Recommended:

1. Modern quantum mechanics, J. J. Sakurai, Addison-Wesley
2. Advanced quantum mechanics, J. J. Sakurai, Addison-Wesley
3. Elements of Group Theory for Physicists, 3rd ed., A. W. Joshi, Wiley
4. Quantum Field Theory: The Why, What and How, 1st ed., Thanu Padmanabhan, Springer
5. Relativistic Quantum Mechanics, J. D. Bjorken, Sidney D. Drell, McGraw-Hill

Core 3.3 : General and Computational Lab III **120 Class Hours**

Unit I : General Laboratory III

Course Outcome: To perform and analyze results of some standard experiments. To give the students exposure to basic measurement techniques and ample scope of analyzing the experimental data. To motivate students in innovative designing of experimental techniques.

1. Quincke's Tube method of determination of paramagnetic susceptibility of salts.
2. Determination of Lande 'g' factor using Electron Spin Resonance technique.
3. Determination of magnetoresistance of semiconductor
4. Acousto-optical effect using Piezo-electric crystal and determination of velocity of ultrasound in a non-polar liquid.
5. Determination of e/m by Millikan's Oil drop method.
6. Study of Iodine absorption spectrum.
7. β-spectroscopy.
8. γ-spectroscopy.

* Some more experiments may be introduced as and when available.

Recommended Books:

1. Principles of Magnetic Resonance, C. P. Slichter, Harper & Row
2. Electricity, Magnetism and Atomic Physics (Vol. I), Fewkes and Yarwood, Oxford IBH
3. Solid State Physics, N. W. Ashcroft and N. D. Mermin, Saunders College
4. Fundamentals of Molecular Spectroscopy, C. N. Banwell, Tata McGraw-Hill

Unit II : Computater Simulation

Course Outcome: Students will be able (i) to model a physical problem in terms of mathematical formulation and subsequent code development and explore the properties of the model by simulation; (ii) to generate random numbers of different probability distribution; (iii) to carry out Monte Carlo simulation.

Simulation Studies on the following problems:
1. Problems of Classical mechanics which involve solution of coupled ODE's (For example: Coupled Oscillation) and visualization
2. Chaotic maps (For example logistic map)
3. Problems involving wave equation and Poisson's equation
4. 1D Schrödinger equation: bound state and scattering problem
5. Monte Carlo technique: Generation of uniform variate, exponential variate and Gaussian variate, Metropolis algorithm. Random walk, Ising system

Recommended Books:
1. Introduction to Computational Physics : Tao Pang, Cambridge University Press
2. Computational Physics: Problem Solving with Computers : R.H. Landau, Wiley-Interscience

DSE 1 **60 Lectures**

a) Advanced Condensed Matter Physics I

Course outcome: To extend the learner's training in the core course on Condensed Matter Physics. To familiarize the learner with some areas of recent interest in Consed Matter Physics. To prepare the learner for taking a further advanced course in Condensed Matter Physics.

1. The many-electron problem and the Hartree-Fock approximation: The basic Hamiltonian – Born-Oppenheimer approximation – reduced electronic Hamiltonian – independent electron approximation of the many-electron problem – simple product and determinantal wavefunction – evaluation of matrix elements of one- and two-body operators; The Hartree-Fock method – Hartree and Hartree-Fock equations – exchange term – Koopman's theorem – Hartree-Fock ground state energy. Hartree-Fock approximation for the interacting electron gas; single particle energy levels – exchange hole – ground state energy; Hartree-Fock excitation spectrum – specific heat at low temperatures. **12L**

2. The interacting electron gas: Occupation number formalism for fermions – the many-electron Hamiltonian in occupation number representation – calculation of matrix elements of one body and two body opeartors – calculation of ground state energy within the first order of perturbation - equivalence with the Hartree-Fock approximation for the interacting electron gas – correlation energy; breakdown of perturbative calculation of ground state energy in the second order – Wigner's calculation; cohesive energy of metals; electron gas as a quantum plasma – screening and plasma oscillations. Hubbard hamiltonian and its ground state – Mott transition (qualitative ideas). **14L**

3. Elements of band theory: Wannier orbitals – tight binding approximation – dispersion relations in 1-d, 2-d and 3-d hypercubic lattice; APW; OPW; pseudopotential method. **8L**

4. Electronic properties: Boltzmann transport equation – relaxation time; electrical conductivity of metals – impurity scattering – ideal resistance at high and low temperatures – U-processes; thermoelectric effects; thermal conductivity; Wiedemann-Franz law. Classical theory of magneto-conductance – Hall effect; k-space analysis of electron motion in a uniform magnetic field – idea of closed, open and extended orbits – cyclotron resonance; energy levels and density of states in a magnetic field; Landau diamagnetism; quantum Hall effect. **14L**

5. Optical properties: Review of the Dielectric properties – Maxwell's equation; the dielectric function – dielectric function for a harmonic oscillator; dielectric loss of electrons; Kramers-Kronig relations; interaction of phonons and electrons with photons; interband transition – direct and indirect transition; absorption in insulators; optical properties of metals – skin effect and anomalous skin effect. **12L**

Recommended Books:

1. The Wave Mechanics of Electrons in Metals, S. Raimes (North Holland)
2. Many-Electron Theory, S. Raimes (North Holland)
3. Elementary Excitations in Solids, D. Pines (W. A. Benjamin)
4. Advanced Solid State Physics, P. Phillips (Westview)

5. Solid State Physics, N. W. Ashcroft and N. D. Mermin (Saunders College)
6. Band Theory and Electronic Properties of Solids, J. Singleton (Oxford)
7. Introduction to Solid-State Theory, O. Madelung (Springer)
8. Condensed Matter Physics, 2nd ed., M. P. Marder (Wiley)
9. Electronic Properties of Materials, 3rd ed., R. E. Hummel (Springer)
10. Basic Solid State Physics, A. Raychaudhuri (Levant)
11. The Modern Theory of Solids, F. Seitz (Dover)
12. Principles of the Theory of Solids, 2nd ed., J. M. Ziman (Cambridge)

b) Astrophysics I

Course outcome: To extend applicability of the learner's training in various core courses of Physics to the arena of Astrophysics. To familiarize the learner with various facets of theoretical Astrophysics and also to introduce the learner to the current status of observational Astronomy. To prepare the learner for taking a further advanced course in Astronomy and Astrophysics.

1. Introduction: Sun, Planets and other objects in the solar system, Stellar magnitude and color, Astronomical distance and its measurements, Cepheid variables, Optical, X-ray, Infra-red, Radio telescopes. **6L**

2. Stellar Structure: Hydrostatic stability, Virial theoram, Lane-Emden equations, Equations of states, Polytrops, Solutions of Lane-Emden equation. **10L**

3. Energy transport in Stars: Radiative, Conductive and Convective transport, Diffusion equation, Eddington Luminosity. **10L**

4. Formation and evolution of stars: Interstellar dust and gas, Formation of protostars, Classification of stars, Evolutions of different initial masses of protostars, H—R diagram, Main-sequence evolution and post-main-sequence evolution, Nucleosynthesis, Supernova, Synthesis of very heavy elements, Remnants. **14L**

5. Cold compact objects: White dwarf, Degenerate electron gas, Chandrasekhar limit, Neutron stars, General relativistic effect, Pulsar, Black hole. **14L**

6. Binary stars: Various types of binaries. **2L**

7. Large-scale structures: Clusters of galaxies, Formation of galaxies, Classification, The Milk way and local group of galaxies, Active galactic nuclei, Quasars. **4L**

Recommended Books:

1. Theoretical Astrophysics, Vol II: Stars and Stellar Systems, T. Padmanabhan, Cambridge University Press.
2. High Energy Astrophysics, 3rd ed., Malcolm S. Longair, Cambridge University Press.
3. Introduction to Stellar Astrophysics, Volume 1: Basic Stellar Observations and Data, 1st ed., Erika Böhm-Vitense, Cambridge University Press.
4. Introduction to Stellar Astrophysics, Volume 3: Stellar Structure and Evolution, 1st ed., Erika Böhm-Vitense, Cambridge University Press.
5. The Stars: Their structure and Evolution, R.J.Tayler, Springer-Verlag
6. Radiative Process In Astrophysics, George B. Rybicki, Alan P. Lightman, John Wiley & Sons.

DSE 2 : Seminars and Colloquia **60 Class Hours**

Course outcome: To train the learner to systematically review a scientific topic and present the finding in the form of a written report. To familiarize the learner to defend the work in the form of a general seminar lecture. To introduce somewhat advanced topics that are generally not included in the PG curriculum.

Each student has to carry out under the supervision of one/ two supervisor(s) a review on a suitable advanced topic related to the Core / DSE courses taught upto the 3rd semester course.

At the end of the course the student has to present the student's findings in the form of a seminar lecture. The student also has to submit a report on the findings in the form of a short dissertation.

GEC : Elements of Modern Physics **60 Lectures**

(*For students from other departments*)

Course outcome: To familiarize the students from non-Physics programme with the outline of recent developments of modern physics. To promote the perspective of inter-disciplinary study that involves knowledge of quantum physics and relativity.

Unit 1: Relativity and Early Quantum theory **30L**

1. Relativity: Galilean transformation – inconsistency with classical electromagnetic theory – postulates of special relativity – derivation of Lorentz transformation formula – relativity of simultaneity – time dilation – length contraction – velocity addition – Doppler effect (longitudinal and transverse) – twin paradox – relativistic momentum – mass-energy relation – $E^2–p^2c^2$ as a relativistic invariant – massless particles; space-time intervals – spacelike and timelike intervals – light cone – principle of equivalence – rudiments of general relativity (qualitative) – bending of light under gravity – gravitational red shift – black holes (qualitative). **16L**

2. Early Quantum Theory: Light as a classical electromagnetic wave – Blackbody radiation – Rayleigh-Jeans formula – ultraviolet catastrophe – Planck's formula – photoeletric effect – Einstein's theory – idea of light quantum– Compton effect – experiments of G. P. Thomson and of Davisson and Garmer – wave nature of electron –application to electron microscopy – wave-particle duality – de Broglie hypothesis – matter waves – probabilistic interpretation – uncertainty principle – gedanken experiment with gamma ray microscope; application of uncertainty principle to a particle in a box (one dimension) – idea of quantisation of energy – discrete spectral lines of atoms and review of Bohr's model of atom – Bohr's quantization condition from the uncertainty relation. **14L**

Unit 2: Quantum Mechanics and Elements of Spectroscopy **30L**

3. Quantum Mechanics: Postulates of quantum mechanics – Schrödinger equation – stationary state solution – time-independent Schrödinger equation as an eigenvalue equation – normalization of wave function – well-behaved wave function – linearity and superposition – expectation value of an operator – particle in a one-dimensional box – energy eigenvalues and eigenfunctions – calculation of probability density – correpondence principle – finite potential well – spreading of wave function across the wall of the well – tunneling through a finite potential barrier – application in alpha decay of nuclei – idea of scanning tunneling microscope – one-dimensional harmonic oscillator – eigenvalues and eigenfunctions (results without formal derivation) – graphical representation of probability density for ground and first two excited states – hydrogen atom problem – energy eigenvalues and tabulation of first five eigenfunctions (no derivation) – three quantum numbers – principal quantum number and quantization of energy – orbital quantum number and angular momentum – magnetic quantum number and space quantization – uncertainty principle and space quantization – probability density and radial and angular probability density – quantum mechanical meaning of the Bohr radius – selection rule – normal Zeeman splitting in a magnetic field. **16L**

4. Elements of Spectroscopy: Electron spin (as an internal degree of freedom, no classical analogue) – Stern-Gerlach experiment – spin magnetic moment – exclusion principle – antisymmetric wavefunctions of fermions – explaining sequence of atoms in periodic table – variation of ionization energy and atomic size in the periodic table – transition elements – Hund's rule – spin-orbit coupling – total angular momentum – *LS* and *jj* coupling (vector atom model) – term symbols – atomic spectral lines of H, He and Na (qualitative) – characteristic x-ray spectra – Moseley's law – Auger effect (qualitative); molecular bonds – H_2 + molecular ion – H_2 molecule – rotational levels of a diatomic molecule (rigid rotor) – selection rule – rotational spectra – vibrational spectra of diatomic molecule – electronic spectra – fluorescence and phosphorescence (qualitative). **14L**

Recommended Books :

1. Concepts of Modern Physics, 6^{th} ed., A. Beiser, McGraw-Hill
2. Quantum Physics, 2^{nd} ed., R. Eisberg and R. Resnick, John Wiley
3. Berkeley Physics Course, vol. 1, Mechanics, C. Kittel et. al., McGraw-Hill
4. Berkeley Physics Courase, vol. 4, Quantum Physics, E. H. Wichman, McGraw-Hill
5. Sears and Zemansky's University Physics, 12^{th} ed., H. D. Young et. al., Addison-Wesley
6. Basic Concepts in Relativity and Early Quantrum Theory, 2^{nd} ed. R. Resnick and D. Halliday, John Wiley

Semester IV

Core 4.1 : Grand Viva   60 Class Hours

Course outcome: To develop problem-solving skill and deeper understanding in core areas of Physics as well as problems of interdisciplinary nature. To help the student prepare for taking a professional career in Physics. To train the student address physics problems in National and International level entrance examinations for further progression in their career.

The student will be trained to solve problems in an interactive mode. This will include syllabi of all the theoretical as well as lab courses taught upto the 4th semester PG class. Recapitulation of topics learnt at the UG level will also be addressed.

The assessment will be in the form of viva-voce.

Recommended Books:

1. Classical Mechanics, 3rd ed., T. W. B. Kibble (Longman)
2. Classical Dynamics of Particles and Systems, 5th ed., S. T. Thornton and J. B. Marion (Thomson)
3. Introduction to Electrodynamics, 4th ed., D. J. Griffths (Pearson)
5. Statistical Mechanics, R. Kubo (North-Holland)
6. Numerical Mathematical Analysis, 6th ed., J. B. Scarborough (Oxford)
7. Schaum's Outlines Complex Analysis, 2nd ed., M. R. Spiegel et. al. (McGraw Hill)
8. Schaum's Outlines Vector Analysis, M. R. Spiegel (McGraw Hill)
9. Schaum's Outlines Theoretical Mechanics, M. R. Spiegel (McGraw Hill)
10. Problems in Electrodynamics, 2nd ed., V. V. Batygin and I. N. Toptygin (Academic Press)
11. Problems in Qunatum Mechanics, F. Constantinescu and Magiyari (Pergamon)
12. Solid State Physics Problems and Solutions, L. Mihaly and M. C. Martin (Wiley)
13. Princeton Problems in Physics with Solutions, N. Newbury et. al. (Princeton)
14. University of California, Berkeley Physics Problems with Solutions, Min Chen (Prentice-Hall India)
15. All other relevant books referred to under different paper codes.

DSE-3 **60 Lectures**

a) Quantum Field Theory

Course outcome: Course outcome: To learn the basic principles of field quantization and to equip the student for taking an advanced course in Quantum Field Theory. To develop understanding of QED. To develop the idea of spontaneous symmetry breaking. To introduce Path integral quantization.

1. Fields from Particle: Path integral and Propagation amplitude for the Non-relativistic Particle, Path Integral for the Jacobi Action, Path integral and propagation amplitude for the Relativistic Particle, Discussion of the properties of the relativistic propagator; Interpretation of the relativistic propagator in terms of fields, Antiparticles. **8L**

2. Particle from field quantization: Quantization of real scalar (Klein-Gordon) field, Davies-Unruh Effect: What is a Particle? Quantizing the Complex Scalar Field, Dirac field. **14L**

3. Quantizing the Electromagnetic Field: Electromagnetic field - Problems with quantisation, Radiation gauge quantisation, Lorentz gauge quantisation (Modifying the classical Lagrangian propagator), Physical states (Gupta-Bleuler quantisation). **8L**

4. Interactions among fields: **20L**
(a) An example among field interactions
(b) Interactions picture and Dyson’s expansion
(c)S-matrix, In and Out states
(d) Wick’s theorem (Normal ordering, Time ordering, 2-point function computation, 4-point function computation using Wick’s theorem, product of 4-fermion operators)
(e) Quantum Electrodynamics - Local gauge invariance, QED interaction Hamiltonian, S-matrix operator in first order, Lowest order processes - S-matrix in second order, Compton scattering, electron-electron scattering
(f) Higher order processes (degree of divergence of QED, Furry’s theorem), Vacuum polarisation diagrams, Lamb shift, electron self energy diagrams, Vertex corrections, 1-oop renormalisation of QED

5. Spontaneous symmetry breaking and the Weinberg-Salam model: **10L**
(a) What is the vacuum ?
(b) Goldstone theorem
(c) Spontaneous breaking of gauge symmetries
(d) Superconductivity
(e) Weinberg-Salam model

Recommended Books:

1. Quantum Field Theory: The Why, What and How, 1st ed., Thanu Padmanabhan, Springer
2. Quantum Field Theory, 2nd ed., Lewis H. Ryder, Cambridge University Press
3. An introduction to quantum field theory, Michale E. Peskin, Daniel V. Schroeder. CRC Press.
4. Field Theory: A modern Primer, Pierre Ramond, Westview Press

b) Nonlinear Dynamics

Course Outcome: To enable the students (i) to analyze the fixed points, phase portrait and the bifurcation of 1-dimensional and 2-dimensional continuous dynamical systems; (ii) to explore the possibility of limit cycle and to analyze relaxation and weakly nonlinear oscillators; (iii) to study the characteristics of chaos in three dimension. Students will be able to analyze iterative maps and the consequent bifurcation and learn about different routes to chaos. They learn about fractals, Poincare maps, strange attractor and non-linearity in Hamiltonian systems.

1. One dimensional dynamical system: flow, Stability analysis, Uniqueness of the solution, potential. Bifurcations in 1 dimension. **4L**

2. Flows on a circle. Non uniform oscillator, Firefly synchronization. **3L**

3. Linear systems –Stability analysis. Calculation of stable and unstable manifolds for saddle points. **2L**

4. 2-dimsional non linear dynamical system- linearization, phase portrait, Index theory, Limit cycle. Poincaré- Bendixon theorem, relaxation oscillators, bifurcation in 2 dimensions, Hopf bifurcation, oscillating chemical reactions, hysteresis in the driven pendulum. **18L**

5. Chaos : Lorentz equations , strange attractor, Lorentz map **3L**

6. One dimesional maps: numerical results and analysis – logistic map as a test case, fixed points and stability analysis for 1-D iterative maps, period doubling, periodic windows, chaos, Liapunov exponent, Feigenbaum’s similarity theorems, Renormalization Group approach. **6L**

7. Fractals: Idea of fractals, generation and properties of Cantor set, Koch curve, Sierpenskii gasket etc. Dimension of fractals – similarity dimension, box dimension, correlation dimension. **4L**

8. Strange Attractor: Baker’s map, Henon map. Rossler system, forced double well oscillator. **4L**

9. Hamiltonian system: Conservative nature, symplectic structure, solution in terms of action-angle variable. **2L**

10. Condition of integrability: Statement of the condition, existence of phase space tori. Regular motion in integrable systems – periodic and quasi-periodic nature. **2L**

11. Introduction of non-integrable perturbation: Canonical perturbation approach, dissolution of comensurable tori, statement of KAM theorem. **2L**

12. Poincaré map & stroboscopic map: Visual representation of motion in 2-D. Birkoff's theorem, Breaking of integrable tori into smaller structure. **2L**

13. Emergence of chaos: Heteroclinic tangle and chaos -- visual representation of chaos. Standard map and visual demonstration of emergence of chaos. **2L**

14. Examples of integrability and chaos: In astrophysical context, in billiard models of 2D electron gas, etc. **2L**

15. EBK quantisation scheme and its failure in non-integrable systems. **2L**

16. Introductory idea of quantum chaos. **2L**

Recommended Books:

1. Nonlinear Dynamics and Chaos: S.H. Strogatz.
2. Chaos, An Introduction to Dynamical System: Alligood, Sauerkraut & York
3. Chaos and Non-linear Dynamics: R.C. Hilborn
4. Chaos in Dynamical System: E. Ott
5. Chaos and Integrability in Nonlinear Dynamics: M. Tabor

DSE 4 **60 Lectures**

a) Advanced Condensed Matter Physics II

Course Prerequisite: Student should have attended Advanced Condensed Matter Physics I.

Course outcome: To introduce some of the advanced areas of Condensed Matter Physics that remain at the focus of recent research interest. To enable the learner to identify and solve toy problems that gives the flavour of hands-on experience of research in these areas.

1. Lattice Dynamics: Classical theory of lattice vibrations under harmonic approximation – dispersion relation – acoustic and optical modes – case of monatomic simple cubic lattice – frequency distribution function; normal coordinates and phonons – occupation number representation of the lattice Hamiltonian; thermodynamics of phonons; Lindemann formula for melting; phonon-phonon interaction – thermal conductivity of insulators; inelastic scattering of neutrons by the vibrating lattice – Debye-Waller factor. **12L**

2. Magnetism: Landau diamagnetism; magnetically ordered solids – electrostatic origin of magnetic interaction – dipolar interaction – spin Hamiltonian – Heisenberg and Ising models; direct exchange – superexchange – indirect exchange; spin waves for ferro and antiferromagnetic ordering of spins on a chain – Holstein-Primakoff transformation; itinerant ferromagnetism – Stoner criterion. **16L**

3. Ferroelectricity– dipole theory, polarization catastrophe, $BaTiO_3$, Landau theory of phase transition. **4L**

4. Superconductivity: London's equation – penetration depth – non-local electrodynamics – Pippard’s coherence length – Ginzburg-Landau (GL) theory – GL coherence length – type II superconductors Flux quantization – BCS theory – superconducting gap – Josephson effect – high T_C superconductors. **14L**

5. Disordered Systems: Disorder in the condensed phase of matter – substitutional and topological disorders – amorphous solids and glasses – long range and short range order – atomic correlation function and structure of glasses and liquids; electronic states in a disordered solid – conductance in a disordered array of scatterers – Landauer formula; density of states and band gap – Wearie-Thorpe model – Anderson Hamiltonian – idea of electron localization – mobility edge; scaling aspects of Anderson localization (rudimentary ideas); electrical properties of amorphous semiconductors – idea of variable range hopping; qualitative idea of quasi-crystalline order – Fibonacci sequence – Penrose tilings; introduction to fractal structure – fractal dimension – example. **14L**

Recommended Books:

1. Lattice Vibrations, B. Donovan and J. F. Angress, Chapman and Hall
2. Basic Solid State Physics, A. Raychaudhuri, Levant
3. Lecture Notes on Electron Correlation and Magnetism, P. Fazekas, World Scientific
4. Advanced Solid State Physics, P. Phillips, Westview
5. Solid State Physics, N. W. Ashcroft and N. D. Mermin, Saunders College
6. Magnetism in Condensed Matter, S. Blundell, Oxford
7. Theory of Magnetism, K. Yoshida, Springer
8. Introduction to Superconductivity, M. Tinkham, McGraw Hill
9. Superconductivity, Superfluids and Condensates, J. F. Annett, Oxford
10. Theory of Superconductivity, J. R. Schrieffer, Addison-Wesley
11. Models of Disorder, J. M. Ziman, Cambridge
12. The Physics of Amorphous Solids, R. Zallen, Wiley

b) Astrophysics II

Course Prerequisite: Student should have attended Astrophysics I.

Course outcome: **T**o equip the learner with the tools and techniques for studying advanced areas of Theoretical Astrophysics and Cosmology. To prepare the learner for taking a further advanced course in Astrophysics and Cosmology.

1. General Relativity: Special relativity, Conceptual foundation of GR and curved space-time, Principle of equivalence, Gravity and geometry, Form of the metric and Newtonian limit, Metric tensor and its properties, Concept of curved space-time, Tangent space and four vectors, Tensor algebra and calculus, Covariant differentiation and parallel transport, Riemann curvature tensor, Geodesic and particle trajectories in gravitation field. **20L**

2. Einstein's field equations: Einstein's field equation, Definition of the stress tensor, Bianchi identities and conservation of the stress tensor, Einstein's equation for weak gravitational fields and the Newtonian limit. **4L**

3. Schwarzschild metric and related topics: Derivation of the metric and its basic properties, $r = 2m$ surface, Effective potential for particle and photon orbits in Schwarzchild metric, Deflection of ultra-relativistic particles, Gravitational red-shift. **6L**

4. Standard Cosmology: The structure of the universe, Cosmological principle, FRW model (closed, open and flat universe), Critical density, Perfect fluid and dynamical equations of cosmology, Hubble's law, Cosmological constant, de Sitter universe, Composition of the energy density of the universe, Dark matter, Dark energy. **20L**

5. Early Universe : Big Bang model, Thermodynamics of the early universe, Thermal history of the universe, Baryogenesis, Nucleosynthesis Primordial Neutrinos,Microwave background radiations, Anisotropy, Age of the universe. **10L**

Recommended Books:

1. General Relativity and Cosmology, J. V. Narlikar, Macmillan India

2. General Relativity, I. R. Kenyon, Oxford

3. Classical Theory of Fields, L.D. Landau & E.M. Lifshitz (Volume 2 of A Course of Theoretical Physics) Pergamon Press.

4. Gravitation: Foundations and Frontiers, T. Padmanabhan 1st ed., Cambridge University Press

5. Theoretical Astrophysics : Galaxies And Cosmology, Vol 3, 1st ed., T. Padmanabhan, Cambridge University Press

6. First course in general relativity, 2nd ed., B. F. Schutz, Cambridge University Press

7. Introduction to Cosmology, 3rd ed., J. V. Narlikar, Cambridge University Press

DSE 5 **120 Class Hours**

a) Condensed Matter Physics Lab

Course Prerequisite: Student should have attended Advanced Condensed Matter Physics I & II.

Course ***outcome:*** To introduce some experiments in condensed matter physics closely related to the Advanced Condensed Matter Special Paper courses. To train the students in handling relatively more sophisticated instruments. To encourage innovative extension of experimental techniques. To analyze experimental data.

List of experiments:

1) Measurement of Dielectric constant and to determine the Ferro-electric to Para-electric transition temperature of Barium Titanate.
2) Study of variation of Hall coefficient with temperature in p-type semiconductor.
3) Study of Hall effect in metals (both electron and hole carriers).
4) Determination of susceptibility of solid by Gouy's method.
5) Study Photoluminescence curve of alkali halides.
6) Determination of T_C of a superconductor and observation of Meissner effect.
7) Study of Farady Rotation.

* Some more experiments may be introduced as and when available.

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b) Astrophysics Lab

Course Prerequisite: Student should have attended Astrophysics I & II.

Course outcome: To train the learner's to operate astronomical telescopes to collect data and further introduce them to the the hands-on techniques for using Astronomical data.

List of experiments:

1) To study the solar limb darkening effect and measuring limb-darkening of Sun.
2) To study the power pattern of various antennae.
3) Polar alignment of an astronomical telescope and measuring declination of Polaris.
4) Measuring extinction of the atmosphere in B, V, and R bands.
5) Differential photometry of a programme star versus a standard star
6) Effective temperature of a star by B-V photometry
7) Night sky brightness with a photometer.
8) Using ds9 astronomical imaging and data visualization application.
9) Study of Farady Rotation.

* Some more experiments may be introduced as and when available.

Recommended books:

1. Astronomy With Your Personal Computer, Peter Duffett-Smith, Cambridge University Press.
2. Practical Astronomy With Your Calculator, Peter Duffett-Smith, Cambridge University Press.
3. Observational Astronomy, 2nd ed., D. Scott Birney, Guillermo Gonzalez, David Oesper, Cambridge University Press.

Core 4.2 : Project

Course outcome: To train the learner to investigate an open problem that requires ability of working out problems independently. To give a flavour of hands-on experience in reserach work. To enable the learner to prepare the finding in the form of a dissertation. Also to enable the learner to present and defend the work carried out in the Major Project.

Each student has to carry out under the supervision of one/ two supervisor(s) a project work on a topic related to recent research interest in physics. In the project work the student is expected to perform some theoretical/experimental/computational investigation. In some exceptional cases the project may concentrate on an extensive review of a suitable advanced topic related to the curriculum but well beyond the scope of the M. Sc. syllabus.

1. The student has to submit a dissertation (both soft and hard copies) presenting the findings of the work.

2. The student, at the end of the course, has to defend the Project work carried out by the student in the form of an oral presentation.

● The student has to be given a minimum of 02 office hours per week to interact with the respective supervisor.