West Bengal State University

Post-Graduate Syllabus for Physics

(effective from academic session 2016-2017)

Programme-specific objective

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.

M.Sc. PART I

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FIRST SEMESTER

Theory Courses

216101 MATHEMATICAL METHODS FOR PHYSICS 50 Marks = 4 CP
216102 CLASSICAL MECHANICS 50 Marks = 4 CP
216103 THERMODYNAMICS & STATISTICAL MECHANICS 50 Marks = 4 CP
216104 QUANTUM MECHANICS I 50 Marks = 4 CP

Laboratory Course

216107 COMPUTER LAB I 50 Marks = 4 CP
216108 GENERAL LAB I 50 Marks = 4 CP

SECOND SEMESTER

Theory Courses

216201 NUCLEAR AND PARTICLE PHYSICS 50 Marks = 4 CP
216202 CONDENSED MATTER PHYSICS 50 Marks = 4 CP
216203 CLASSICAL THEORY OF FIELDS & ELECTRODYNAMICS 50 Marks = 4 CP
216204 QUANTUM MECHANICS II 50 Marks = 4 CP

Laboratory Courses

216207 COMPUTER LAB II 50 Marks = 4 CP
216208 GENERAL LAB II 50 Marks = 4 CP

M.Sc. PART II

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THIRD SEMESTER

Theory Courses

216301 QUANTUM MECHANICS III 50 Marks = 4 CP
216302 ADVANCED STATISTICAL MECHANICS 50 Marks = 2 CP
216303 ATOMIC AND MOLECULAR PHYSICS 50 Marks = 4 CP
216304 SPECIAL PAPER I 50 Marks = 4 CP
216305 SEMINARS AND COLLOQUIA 50 Marks = 2 CP

Laboratory Courses

216307 COMPUTER LAB III 50 Marks = 2 CP
216308 ADVANCED EXPERIMENTS 50 Marks = 6 CP

FOURTH SEMESTER

Theory Courses

216401 SPECIAL PAPER II 50 Marks = 4 CP
216402 GRAND VIVA 50 Marks = 4 CP
216403 ELECTIVE 50 Marks = 4 CP

Laboratory & Project Courses

216407 Laboratory Course (Special Paper) / Minor Project* 50 marks = 4 CP

[There will be laboratory course on the special paper chosen. *Only if the special paper is of theoretical nature (Quantum Field theory) the student has to work for a minor project in lieu of the laboratory course.]

216408 MAJOR PROJECT 100Marks = 8 CP

[CP : Credit Point]

Detailed Syllabus

Sem I

216101 Mathematical Methods (60 hours)

Course objective: Every branch of physics depends heavily on mathematical methods. Objective of this course is to enable to students (i) to understand and apply techniques of solving of second order linear ordinary differential equation, (ii) to understand and apply the theory of functions of complex variable (iii) to be able to handle the special functions used in physics and (iv) to use the integral transforms in solving physics problems.

1. **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

2. **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.

3. **Special Functions:**
   Basic properties (recurrence and orthogonality relations, series expansion) of Bessel, Legendre, Hermite and Laguerre functions.

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

Books:

1. Applied Mathematics for Engineers and Physicists, L. A, Pipes, L. R. Harvill, 3rd. ed. (McGraw-Hill)
2. Mathematical Methods for Physicists, Arfken & Weber, 7th. ed. (Wiley)
3. Mathematics for Physicists, Denney and Krzywicki (Dover)
4. Complex Variables and Applications, Brown & Churchill (McGraw-Hill)
5. Mathematical Methods for Physics and Engineering: A Comprehensive Guide, K. F. Riley, M. P. Hobson, S. J. Bence, 3rd ed. (Cambridge)

216102 Classical Mechanics (60 hours)

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

1. Typical problems in mechanics at undergraduate level: a) without friction, b) with friction
2. Conservation of momentum, energy
3. Rotation- 2 dimensional (Angular momentum and Torque); Generalization- 3 dimensional (Angular momentum vector, inertia tensor, Euler's equation, gyroscope)
4. Accelerated frame of reference (Foucault's pendulum, tides)
5. Central force motion; Kepler's laws.
6. Lagrangian formalism: Stationarity of Action as the basic law of Physics. Revisiting 1-7 on the basis of Lagrange's equation, applications of Lagrange's equation: velocity dependent potential; symmetry and conservation principles; small oscillations, normal modes and frequencies, the heavy symmetric top.
7. 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.
8. 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.
9. 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.
10. Hamilton Jacobi theory: The Hamilton-Jacobi equation for Hamilton's principle function; The harmonic oscillator problem; Hamilton's characteristic function; Action angle variables.

Books:

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

216103 Thermodynamics & Statistical Mechanics (60 hours)

Course objective: To enable the student to grasp the fundamental principles of Statistical Mechanics as a microscopic foundation of Thermodynamics. 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.

1. Fundamentals and microcanonical systems

Objective of statistical mechanics; Method of statistical mechanics, macrostates, microstates, probability, ensemble, postulate of equal a priori probability (PEAP).

2. Interactions between two systems - thermal, mechanical and diffusive

Thermal interaction-concept of temperature and entropy, S=k1nΩ relation for a microcanonical system, 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.

3. Canonical systems

Partition function; Equation of State; Energy fluctuation and C_v; Microcanonical and canonical distribution using Lagrange's undetermined multiplier; Entropy of ideal gas mixture, Gibbs' Paradox.

4. Grand canonical system

Partition function; Equation of state; Fluctuation in the number of particles; PV=KT 1nZ relation.

5.Classical non - ideal gas

Mean field theory and Van der Wall's equation of state; Cluster integrals and Mayer-Ursell expansion.

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; Identical particles-B-E and F-D distributions.

7. Ideal Bose and Fermi gas

Equation of state; Bose condensation; Equation of state of ideal Fermi gas; Fermi gas at finite T.

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.

Books:

1. Statistical Mechanics, 2nd ed., R. K. Pathria (Butterworth Heinmann)
2. Berkeley Physics Course (vol. 5), F. Rief (McGraw-Hill)
3. Thermodynamics and Statistical Mechanics, W. Greiner, L. Neise and H. Stocker (Springer)
4. Statistical Mechanics, 2nd ed., K. Huang (Wiley)
5. Equilibrium Statistical Physics, 3rd ed., M. Plischke and B. Begersen (World Scientific)

216104 Quantum Mechanics I (60 hours)

***Course objective**:* Students will know and understand the concept of vector space and will be able to apply the same immediately in formulation of Quantum Mechanics as well as in many other fields of quantitative science. Students will be exposed to the postulatory approach of quantum mechanics. Students will be able to solve bound states and tunneling problems in one dimension and will also be familiar with angular momentum algebra. These will prepare the student to take a more advanced course in Quantum Mechanics.

1. Towards Quantum mechanics: de Broglie Waves and the Heisenberg Microscope.

2. Mathematical preliminaries: Vector spaces, inner product, Hilbert space, Linear Operators, Eigen values and Eigen vectors, hermiticy, commutation and simultaneous eigenstates, complete set.

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

4.**One dimensional problems:** Bound States, Reflection and Transmission, Tunneling through barriers.

5. 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.

Books:

1. Elements of Quantum Mechanics, B. Dutta Roy (New Age)
2. Quantum Mechanics: Concepts and Applications, N. Zettili (Wiley)
3. Quantum Mechanics, C. Cohen-Tannoudji, B. Diu, F. Laloe (Wiley VCH)
4. Quantum Mechanics, L. Schiff (McGraw-Hill)
5. Vector Spaces and matrices, R.M. Thrall, L. Tornheim (Dover)
6. Introduction to Matrices and Linear Transformation, D.T. Finkbeiner (Courier Corporation)
7. Introduction to Quantum Mechanics, D.J. Gritffith, D.F. Scröfter (Cambridge University Press)

216107   Computer Lab I

Course objective: 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. Each year problem sets need to be different. Also to make the student familiar with Computer Interfacing.

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, user defined functions, functions with default arguments, functions with arbitrary arguments. Lamda function, list comprehension, turtle graphics, Class, methods (with self and also with self-other), instantiation, inheritance, operator overruling, File I/O, module.

Students should write programs
1) To Calculate Mean median mean of point data and classified data.
2) To Calculate Frequencies in user given number of classes from a given distribution of data.
3) To draw geometric figures and plot data on the turtle canvas.
4) To generate random noise (using random())
5) To handle vectors and matrices (with class and methods)
6) To Generate data according a given equation, adding noise and extracting parameters using least square method.

Computer interfacing using PHOENIX kit developed by UGC IUAC, New Delhi

216108   General Lab I

Course *objective*: 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.

1) Determination of Hall coefficient of p and/or n type semiconductor

2) Frank Hertz experiment

3) Determination of e/m of electron using crossed electric and magnetic fields

4) Determination of Dielectric Constant of a non-polar organic liquid

5) Transfer Characteristic of Enhancement type MOSFET

Semester II

216201 Nuclear and Particle Physics (60 hours)

Course objective: 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 Phenomenology
2. Nuclear Models (Liquid drop model, Fermi gas model, Shell model, Collective model)
3. Principle of particle Detectors and Accelerators
4. Alpha, beta and gamma decays
5. Nuclear reactions, fission and fusion
6. Properties and interactions of Elementary particles
7. Symmetries
8. Discrete transformations
9. Neutral kaons, Oscillations and CP violation
10. Standard Model

Books:

1. Atomic and Nuclear Physics (Vol. 2), S. N. Ghosal (S. Chand)
2. Introductory Nuclear Physics, K. S. Krane (Wiley)
3. Introduction to Nuclear and Particle Physics, Das & Ferbel (World Scientific)
4. Introduction to Elementary Particles, D. J Griffiths, 2nd ed. (Wiley)

216202 Condensed Matter Physics (60 hours)

Course objective: To familiarize the student with the basic facts and underlying principles of Condensed Matter Physics. To develop the skill of formulating and systematically solving problems in Condensed Matter Physics that will find applications in Material Physics as well as other related branches of Physics. To prepare the student to take advanced course in Condensed Matter 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

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

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, Electrostatic screening in a Fermi gas – The Mott transition.

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; motion of electrons in super-lattices; motion of atoms in an optical potential; Landau levels - de Haas van Alphen effect and Integer quantum hall effect

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.

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 (revisiting 2^{nd} semester), 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, Phonon spectroscopy – inelastic scattering of neutron, Mossbauer effect.

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 and EMR, 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.

8. Superconductivity: Phenomenological description – critical temperature, persistent current, thermoelectric properties, The Meissner effect; Type I and II superconductors, specific heat, energy gap, The BCS ground state, Quantization of magnetic flux and Josephson effect, Vortex state (qualitative discussions); high T_C superconductor (informative only)

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

Books:

1. Introduction to Solid-state Physics, C. Kittel, 7^{th} ed. (Wiley)

2. Elementary Solid State Physics, M. A. Omar (Pearson)

3. Solid State Physics, N. W. Ashcroft and N. D. Mermin (Saunders College)

4. Solid State Physics, Ibach and Luth (Springer)

5. Physics of Semiconductor Devices, Sze, (Wiley)

6. Oxford Series in Condensed Matter (Oxford university Press)

216203 Classical Field Theory & Electrodynamics (60 hours)

Course objective: 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.

1. Introduction to tensor;
2. Special Relativity in Tensor Notation;
3. Generalization of classical particle mechanics to classical field theory and field theoretic action;
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, Dynamic term for gauge field, Electromagnetic field tensor, Action for electromagnetic field and the Maxwell's equations in covariant form, Dual field tensor.
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.
6. Motion of charged particles in uniform and non-uniform electric and magnetic fields, Diffusion across magnetic fields, Time-varying electric and magnetic fields, Adiabatic invariants: first, second and third adiabatic invariants.

Books:

1. Classical Theory of Fields, (Volume 2 of A Course of Theoretical Physics), L.D. Landau & E.M. Lifshitz (Pergamon Press)
2. Gravitation: Foundations and Frontiers, T. Padmanabhan, 1^{st} ed. (Cambridge University Press)
3. Introduction to Electrodynamics, D. J. Griffiths, 4^{th} ed. (Pearson)
4. Classical Electrodynamics, J. D. Jackson, 2^{nd} ed. (Wiley)
5. Classical Electromagnetic Radiation, M. A. Heald & J. B. Marion (Saunders College)

216204 Quantum Mechanics II (60 hours)

Course objective: To apply quantum mechanics in solving bound state problems in thhree dimension. To learn approximation methods like WKB, time-independent and time-dependent perturbation and variational method and to apply these methods in solving different problems. To learn the techniques of scattering problems in quantum mechanics: to be applied in various branches of modern nuclear and subatomic physics.

1) Bound State Central Field problems in three dimensions.

2) 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.

3) Approximate methods for stationery states: Time-independent perturbation, the variational method, the Born-Oppenheimer approximation, the WKB approximation. As ample examples from atomic and molecular physics should be given, relevant background material such as the Physics of identical particles, the Pauli principle must be clarified.

4) Approximate methods for time dependent problems: Solvable two level system, time dependent perturbation theory, interaction picture the adiabatic and sudden approximations.

Books:

1. Elements of Quantum Mechanics, B. Dutta Roy (New Age)
2. Quantum Mechanics: Concepts and Applications, N. Zettili (Wiley)
3. Quantum Mechanics, C Cohen-Tannoudji, B. Diu, F. Laloe (Wiley VCH)
4. Quantum Mechanics, L. I. Schiff (McGraw-Hill)
5. Introduction to Quantum Mechanics, D. J. Griffiths, 2nd ed. (Pearson)
6. Physics of Atoms and Molecules, Bransden & Joachain (Pearson)
7. Quantum Mechanics (Course in Theoretical Physics, vol. 3), Landau & Lifshitz, 3rd ed. (Pergamon)

216207   Computer Lab II

Course objective: To learn the basic numerical methods and to develop the skill of implementation of them in program codes in solving simple problems in numerical physics. Students will be able to develop codes for a given numerical method and compare the efficiency of different alternative methods.

Numerical methods: Gauss Jordan Elimination with pivoting

Solving linear system of equations, determinant, inverse of a matrix

Root searching of algebraic equation (1D and Multidimensional)

Integration

Ordinary Differential equation (1D and Multidimensional)

Interpolation

Matrix diagonalization.

216208 General Lab II

Course objective: 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. Measurement of band gap of a semiconductor using the 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.

5. Determination of specific charge of electron by the method of magnetic focusing method

6. Determination of Planck's constant using a LED.

7. Particle size Measurement by diffraction of monochromatic LASER.

Some new experiments may be introduced as and when possible.

Sem III

216301 Quantum Mechanics III (60 hours)

Course objective: 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. To introduce the theory of radiative transitions. To prepare the student for taking an advanced course in Quantum Field Theory/ Many Body Physics.

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

2. Group theory in Quantum mechanics: Definitions; Multiplication table; Rearrangement theorem; Subgroups and cosets; Conjugacy Classes; elements, class and factor groups; Class multiplication; Isomorphism and homomorphism; Illustrations with point symmetry groups; 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.

3. Radiative transitions: Interaction of electromagnetic field with one-electron atoms, Perturbation theory for harmonic perturbations and transition rates, spontaneous emissions, selection rules for electric dipole transition, Spin of the photon and helicity, Stark effect, Zeeman effect.

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**.**

Books:

1. Quantum Mechanics, L. Schiff (McGraw-Hill)
2. Group Theory and Quantum Mechanics, M. Tinkham, 3rd ed. (Dover)
3. Elements of Group Theory for Physicists, A. W. Joshi, 3rd ed. (Wiley)
4. Relativistic Quantum Mechanics, Bjorken & Drell (McGraw-Hill)

216302 Advanced Statistical Mechanics (30 hours)

Course objective: 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.
2. Basic postulates: Ergodic hypothesis, Boltzmann hypothesis, equal weights hypothesis.
3. Boltzmann transport equation.
4. Langevin equation, Fokker Planck equation.
5. Phase transitions. Landau theory and elements of scaling and renormalization group.

Books:

1. Fundamentals of Statistical and Thermal Physics, F. Reif (McGraw-Hill)
2. Statistical Mechanics, K. Huang, 2nd ed., (Wiley)
3. Equilibrium Statistical Physics, 3rd ed., M. Plischke and B. Begersen (World Scientific)
4. Statistical Physics: Equilibrium and Non Equilibrium Aspects, J. K. Bhattacharjee (Allied)

216303 Atomic and Molecular Physics (60 hours)

Course objective: To apply the methods of Quantum Mechanics in atomic structure and spectra. To apply Quantum Mechanics in molecular spectroscopy. To understand several experimental effects related to atomic and molecular spectra. To prepare theoretical foundation of students aiming at a research career in the area of spectroscopy.

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.

2. Relativistic correction terms for an one electron atom – fine structure of hydrogenic atoms – normal and anomalous Zeeman effect ; Paschen -Back effect ; Stark effect ; hyperfine structure – magnetic dipolar and quadrupolar hyperfine splitting – isotope shift.

3. Many electron atoms – central field approximation- the Thomas Fermi model – spin-Pauli exclusion principle – 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.

4. Molecular Spectroscopy – Born-Oppenheimer approximation – Rotational spectrum of diatomic molecule – rigid rotor model – Selection rules – intensities – effect of isotropic substitution – non-rigid rotor ; polyatomic molecules ; vibrational spectrum of diatomic molecule; anharmonic effects; vibration – rotation spectrum – breakdown of Born-Oppenheimer approximation ; electronic spectrum – intensity of vibrational – electronic spectrum; Franck-Condon principle – rotational fine structure – Fortrat diagram ; Raman effect – Stokes and anti-Stokes lines – application

Books:

1. Physics of Atoms and Molecules, Bransden & Joachain (Pearson)
2. Fundamentals of Molecular Spectroscopy, C. N. Banwell (Tata McGraw-Hill)

216304 SPECIAL PAPER I (60 hours)

A) Quantum Field Theory I

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

1. Canonical Quantisation and particle interpretation
(a) Real scalar (Klein-Gordon) field, Complex Klein-Gordon field, Dirac field
(b) Electromagnetic field - Problems with quantisation, Radiation gauge quantisation, Lorentz gauge quantisation (Modifying the classical Lagrangian propagator), Physical states (Gupta-Bleuler quantisation)

2. Interactions among fields
(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-loop renormalisation of QED

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

4. Path integral quantisation and Feynmann rules
(a) Generating funcional for scalar fields
(b) Free particle Green's functions
(c) Generating funcional for interacting fields
(d) Phi-4 theory - 2-point, 4-point functions
(e) Fermions and functional methods
(f) Pion-nucleon scattering amplitude, cross-section

Books:
1. Quantum Field Theory, Lewis H. Ryder, 2^{nd} ed. (Cambridge University Press)
2. An Introduction to Quantum Field Theory, M. E. Peskin and D. V. Schroeder (Sarat Book House)
3. Field Theory: A modern Primer, Pierre Ramond (Westview Press)
4. A First Book of Quantum Field Theory, A. Lahiri and P. B. Pal, 2^{nd} ed. (Narosa)
5. A Modern Introduction to Quantum Field Theory, M. Maggiore (Oxford)

B) Astrophysics I

Course objective: To introduce fundamental concepts and basic facts of theoretical Astrophysics. To introduce 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.

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

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

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.

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

6. Binary stars: Various types of binaries, Accretion disc.

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

Books:

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

C) Advanced Condensed Matter Physics I

Course objective: 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.

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).

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.

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.

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.

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)

[Note: Advanced Condensed Matter I is to be introduced right from the Semester 3 class in 2016-'17 academic year]

216305 SEMINARS AND COLLOQUA

Course objective: To train the learner to systematically review a somewhat advanced topic and present the finding in the form of a written report. Also to familiarize the learner to defending the work in the form of a general seminar lecture.

Each student has to carry out under the supervision of one/ two supervisor(s) a review on a suitable advanced topic related to the 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.

216307: Computer Lab III

Course objective: Students will be able to map physical problems to mathematical models to model a physical problem in terms of mathematical model and explore the properties of the model by simulation of the model. To carry out Monte Carlo simulation. To use C as programming language.

1. Progamming in C: Constant and variables, data types, typedef, control structures, std I/O, strings, functions, pointers, file handling, structure, union, dynamic memory allocation, linked list.

2. Simulations: The programming language for numerical calculations may be python (with numpy and scipy module) or c. Visualization should be using python (with turtle/matplotlib) or gnuplot or xmgrace.

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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. Optimization, non linear least square fit.
6. Monte Carlo technique: Generation of uniform variate, exponential variate and Gaussian variate, Metropolis algorithm. Random walk, Ising system

Books:

1. Introduction to Computational Physics : Tao Pang (Cambridge University Pres)
2. Computational Physics: Problem Solving with Computers : R.H. Landau (Wiley-Interscience)
3) Computational Physics: Nicholas J. Giordano (Pretice Hall)

216308 Advanced Experiments

Course objective: To perform and analyze results of some standard experiments. The experiments are so chosen so as to give the students exposure to basic measurement techniques and ample scope of analyzing the experimental data.

1. Quincke's Tube method of determination of paramagnetic susceptibility of salts.
2. Determination of Lande 'g' factor determination by Electron Spin Resonance technique.
3. Study of magnetoresistance of semiconductor
4. Acousto-optical effect using Piezo-electric crystal and determination of velocity of ultrasound in liquid.
5. Determination of e/m by Millikan's Oil drop method.

Some other experiments may be introduced as and when required.

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)

SEM IV

216401 SPECIAL PAPER II (60 hours)

A) Quantum Field Theory II

Course to be offered only to the students having studied the course Quantum Field Theory I in SEM III.

Course objective: To give exposure to applications of Quantum Field Theory in the area of Particle Physics. To introduce basic concepts as well as areas of recent research interest in the field.

1. Properties and Interactions of Elementary particles
(a) Elementary particles
(b) Quantum numbers - Baryon number, Lepton number, Strangeness, Isospin
(c) Gell-Mann - Nishijima relation
(d) Violation of Quantum numbers -Weak interactions, HadronicWeak decays, Semileptonic processes, Electromagnetic processes

2. Symmetries:
(a) Symmetries in the Lagrangian and Hamiltonian formalisms
(b) Symmetries in Quantum mechanics

3. Discrete transformations:
(a) Parity - ex. Parity of --Meson
(b) Violation of Parity
(c) Time reversal
(d) Charge Conjugation
(e) CPT theorem

4. Weak interactions: Decay of the Muon, decay of the neutron

5. Hadronic interactions: Pion-Nucleon interctions - Form of the Pion-nucleon interaction, Yukawa theory of Nuclear forces

6. Standard Model: (a) Quarks as Building blocks of Hadrons
(b) Mesons as Bound Quark states
(c) Need for Color (ex. Quark model for Mesons)

7. Neutral Kaons and CP Violation: (a) Neutral Kaons (b) CP eigenstates of neutral Kaons, Violation of CP invariance

Books:

1. Introduction to Elementary Particles, D. J. Griffiths, 2nd. ed. (Wiley)
2. QUARKS AND LEPTONS: An Introductory Course in Modern Particle Physics, Halzen and Martin (Wiley)
3. Gauge Theories in Particle Physics A Practical Introduction, Aitchison and Hey (Taylor & Francis)
4. An Introductory Course of Particle Physics, P.B.Pal (CRC Press)

B) Astrophysics II

Course to be offered only to the students having studied the course Astrophysics I in SEM III.

Course objective: **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.

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.

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.

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.

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.

Books:

1. General Relativity and Cosmology, J. V. Narlikar (Macmillan India)
2. General Relativity, I. R. Kenyon (Oxford)
3. Classical Theory of Fields, Vol. 2, L. D. Landau and E. M. Lifshitz, (Pergamon)
4. Gravitation: Foundations and Frontiers, T. Padmanabhan 1st ed. (Cambridge University Press)
5. Theoretical Astrophysics : Galaxies And Cosmology, Vol 3, T. Padmanabhan 1st ed. (Cambridge University Press)
6. First course in general relativity, B. F. Schutz, 2nd ed. (Cambridge University Press)
7. Introduction to Cosmology, J. V. Narlikar, 3rd ed. (Cambridge University Press)

C) Advanced Condensed Matter Physics II

Course to be offered only to the students having studied the course Advanced Condensed Matter Physics I in SEM III.

Course objective: To introduce special topics of condensed matter physics closely related to recent research interest. To prepare the student for taking up a more advanced course in theoretical condensed matter physics.

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.

2. **Magnetism:** Paramagnetism in insulators **-** van Vleck paramagnetism – Curie's law – effect of crystal field; paramagnetism in metals – Pauli spin paramagnetism; 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.

3. **Ferroelectricity:** dipole theory, polarization catastrophe, BaTiO3 – Landau theory of phase transition.

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

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.

Books:

1. Lattice Vibrations, Donovan and Angress (Chapman & Hall)
2. Basic Solid State Physics, A. Raychaudhuri (Levant)
3. Theory of Superconductivity, J. R. Schreiffer (Addison-Wesley)
4. Theory of Magnetism, K. Yoshida (Springer-Verlag)
5. Quantum Theory of Solids, C. Kittel (John Wiley)

6. Electron Correlation and Magnetism, P. Fazekas (World Scientific)
7. Models of Disorder, J. M. Ziman (Cambridge)
8. The Physics of Amorphous Solids, R. Zallen (John Wiley)
9. Condensed Matter Physics, 2nd ed., M. P. Marder (Wiley)

[Note: Advanced Condensed Matter II is to be introduced right from the Semester 4 class in 2016-'17 academic year]

216402 GRAND VIVA (60 hours)

Course outcome: To develop problem solving skill in core areas of Physics as well as problems of interdisciplinary nature. To help the student prepare for taking a professional career in Physics.

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.

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.

216403 Elective Paper (60 hours)

a) Biophysics

Course objective: To introduce essential methods of biophysical science including a rudimentary course in non-linear dynamics. To equip the student for following recent developments in the arena of molecular biophysics and theoretical neuroscience.

1. Nonlinear dynamics and its application in biology: One dimensional flow, population growth, Bifurcations in one dimension, Saddle-Node bifurcation, Action Potential in neuron, Transcritical Bifurction, classical model of laser, Supercritical and subcritical pitchfork bifurcations, Spontaneous symmetry breaking, Second order phase transition, catastrophe theory, Model of epidemic, Flow on a circle, nonuniform oscillator, ghosts and bottlenecks, firefly flashing rhythm, Two dimensional flows, Linear systems, Liapunov stability of a system, classification of fixed points of a 2-dim system on the basis of eigenvalues. Phase plane, phase portraits, conservative systems, Index theory, Limit cycles, Hopf bifurcation, Oscillatory chemical reactions, Brusselator, glycolytic oscillation, morphogenesis, Regulation of *lac* operon.

2. Random walk models and conformation, Flory-Huggins theory, Introduction to nucleic acid structure, DNA flexibility, DNA topology, Introduction to protein structure, Protein translocation on DNA, Protein motors.

3. Resting Membrane Potential: Nernst Planck equation, Nernst Potential, Goldmann Solution, GHK equation., Donnan Equillibrium. Channel: reversal potential. Electrical Model of biological membrane: Passive response. Active response. Voltage clamp: voltage gated Na, K current : Hodgkin Huxley models : Space Clamped Hodgkin Huxley equation: Numerical integration, qualitative understanding, action potential -singular perturbation and bifurcations, sustained oscillation. Morris Lecar equation – action potential generation by singular perturbation, theory of Type I and Type II neurons. Cable equation: passive: steady state - idea of space constant and time constant. Space dependent HH equation –numerical results. Homoclinic orbit. Neural Coding: Firing rates and spike statistics, reverse correlation and visual receptive fields. Neural oscillators weak coupling.

Books:

1. Nonlinear Dynamics and Chaos: S.H. Strogatz (Levant)
2. Theoretical Molecular Biophysics: P.O.J. Scherer and S.F. Fischer
3. Mathematical Foundations of Neuroscience: G.B. Ermentrout and D.H. Terman,
4.Theoretical Neuroscience: P. Dayan and L E. Abbott

b) Condensed Matter Physics

Course objective: To introduce major areas of developments in the field of theoretical condensed matter physics. To prepare the student to take a more advanced course in condensed matter physics and to equip the student for taking a research career in condensed matter physics in future.

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.

2. The interacting electron gas: Occupation number formalism for fermions – the many-electron Hamiltonian in occupation number representation – Hartree-Fock approximation for the interacting electron gas; single particle energy levels – exchange hole – ground state energy; equivalence with a first order perturbative calculation – Hartree-Fock excitation spectrum – specific heat at low temperatures; 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.

3. Electronic properties: 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.

4. Magnetism: Magnetically ordered solids – Heisenberg model; spin waves for ferro and antiferromagnetic ordering of spins on a chain – Holstein-Primakoff transformation; itinerant ferromagnetism – Stoner criterion.

5. Superconductivity: Review of basic experimental facts – two-fluid model; London's equation – penetration depth – non-local electrodynamics – Ginzburg-Landau (GL) theory – Flux quantization – GL coherence length – type II superconductors – BCS theory – Bogoliubov transformation – superconducting gap – Josephson effect – high T_C superconductors (qualitative introduction).

Books:

1. The Wave Mechanics of Electrons in Metals: S. Raimes (North-Holland)
2. Many-Electron Theory: S. Raimes (North-Holland)
3. Solid State Physics: N. W. Ashcroft, N. D. Mermin (Thomson)
4. Condensed Matter Physics: M. P. Marder (Wiley)
5. Theory of Superconductivity: J. R. Schreiffer (W. A. Benjamin)
6. Introduction to Superconductivity: M. Tinkham (Dover)

c) Nonlinear Dynamics and Chaos

Course objective: To enable the students to analyze the fixed points, phase portrait and the bifurcation of 1-dimensional and 2-dimensional continuous dynamical systems. To explore the possibility of limit cycle and to analyze relaxation and weakly nonlinear oscillators To study the characteristics of chaos.

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

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

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

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.

5. Chaos : Lorentz equations , strange attractor, Lorentz map

6. One dimesional maps, logistic map: numerical results and analysis, periodic windows, Liapunov exponent.

7. Fractals- Cantor set, Dimension of a self similar fractal, box dimension.

8. Strange Attractor, Henon map. Rossler system, forced double well oscillator.

Books:

1. Nonlinear Dynamics and Chaos: S.H. Strogatz (Levant)

d) Quantum Field Theory:

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

1. Canonical quantisation of free matter fields: Real scalar field, Complex scaklar field, Dirac field

2. Canonical quantization of electromagnetic field: Problems with quantization, Radiation gauge quantization, Lorentz gauge quantisation (Modifying the classical Lagrangian propagator), Physical states (Gupta-Bleuler quantisation)

3. Interactions among fields:
(a) Interactions picture and Dyson's expansion
(b) S-matrix, In and Out states
(c) Wick's theorem (Normal ordering, Time ordering, 2-point function computation, 4-point function computation using Wick's theorem, product of 4-fermion operators), Feynmann rules
(d) 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
(e) Higher order processes (degree of divergence of QED, Furry's theorem), Vacuum polarization diagrams, Lamb shift, electron self energy diagrams, Vertex corrections, 1-loop renormalization of QED

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

4) Path integral quantization:
(a) Generating funcional for scalar fields
(b) Free particle Green's functions
(c) Generating funcional for interacting fields
(d) Phi-4 theory - 2-point, 4-point functions
(e) Fermions and functional methods
(f) Pion-nucleon scattering amplitude, cross-section

Books:

1. Quantum Field Theory, Lewis H. Ryder, 2nd ed. (Cambridge University Press)
2. An Introduction to Quantum Field Theory, M. E. Peskin and D. V. Schroeder (Sarat Book House)
3. Field Theory: A modern Primer, Pierre Ramond (Westview Press)
4. A First Book of Quantum Field Theory, A. Lahiri and P. B. Pal, 2nd ed. (Narosa)
5. A Modern Introduction to Quantum Field Theory, M. Maggiore (Oxford)

[Note: Quantum Field Theory as an Elective Paper is to be introduced right from the Semester 4 class in 2016-'17 academic year]

216407 Laboratory Course (Special Paper) / Minor Project

A) Quantum Field Theory :

Course to be offered only to the students having studied the course Quantum Field Theory I in SEM III.

Course objective: To encourage the student to solve an advanced level problem or take up a review work on a topic related to but not explicitly included in the syllabus of the theoretical papers on Quantum Field Theory.

Minor Project to be assigned by Special paper Instructors.

The evaluation will consist of submission of a written Project Report followed by a presentation by the student.

B) Astrophysics:

Course to be offered only to the students having studied the course Astrophysics I in SEM III.

Course objective: To introduce the student with the basic experimental techniques in Astronomy and Astrophysics. To enable the student handle an astronomical telescope

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

C) Advanced Condensed Matter Physics II

Course to be offered only to the students having studied the course Advanced Condensed Matter Physics I in SEM III.

Course objective: 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.

216408 Major Project

Course objective: 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, and present and defend the same.

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.

The student has to submit a dissertation (both soft and hard copies) presenting the findings of the work. At the end of the course the student has to present the student's findings in the form of a lecture and defend the same.