Barasat Government College
CBCS Syllabus for M.Sc. in Physics
Post Graduate Department of Physics
(Effective from 2021-22)

Programme: M.Sc. in Physics

Programme-specific outcome

- **PSO1:** This course can develop the critical thinking skills of the students through acquired knowledge in major branches of physics.
- **PSO2:** Learn to carry out experiments in basic as well as certain advanced areas of physics¬ such as Condensed Matter Physics, High Energy Physics, Statistical Mechanics and Nuclear & Particle Physics.
- **PSO3:** They learn the deeper meaning of different branches of physics and their¬ interrelationships. The students are also motivated to face competitive examinations and course enhance National and International competency.
- **PSO4:** They learn to tackle and troubleshoot problems during experiments at the labs.¬
- **PSO 5:** They learn the very nature of performing research work in Physics during projects.¬ They can explain their research work results in project seminars.
- **PSO6:** The two-year PG course – Master Degree in Science (M. Sc. Course) gives them¬ enough opportunity to align their mental faculties and attitudes to prepare for the State and National Level Examinations (SLET, NET, UGC-CSIR, DST, UPSC, etc.) for entry to recognized Institutions and Research Organizations (IACS, SINP, SNBNCBS, CGCRI, etc.).
- **PSO7:** The students are motivated for going to abroad for Research Career by virtue of¬ National Overseas Scholarship Schemes after completion of M. Sc. Course in Physics.

SEMESTER-I			
Sl No	**Course Type**	**Topic**	**Credit**
1	**CORE: 1.1 (Theory)**	**Mathematical Methods**	**4**
2	**CORE: 1.2 (Theory)**	**Classical Mechanics**	**4**
3	**CORE: 1.3 (Theory)**	**Quantum Mechanics I**	**4**
4	**CORE: 1.4 (Theory)**	**Electronics & Instrumentation**	**4**
5	**CORE: 1.5 (Practical)**	**General Laboratory**	**4**
SEMESTER-II			
Sl No	**Course Type**	**Topic**	**Credit**
1	**CORE: 2.1 (Theory)**	**Electrodynamics**	**4**
2	**CORE: 2.2 (Theory)**	**Quantum Mechanics II**	**4**
3	**CORE: 2.3 (Theory)**	**Statistical Mechanics**	**4**
4	**CORE: 2.4 (Practical)**	**General Laboratory**	**4**
5	**CORE: 2.5 (Practical)**	**Computer Laboratory**	**4**

SEMESTER-III			
Sl No	Course Type	Topic	Credit
1	CORE: 3.1 (Theory)	Atomic, Molecular and Laser Physics	4
2	CORE: 3.2 (Theory)	Solid State Physics	4
3	CORE: 3.3 (Theory)	Nuclear and particle physics	4
4	DSE: 1 & 2 (Theory) (Choose any two out of three options)	(i) Materials Physics (ii) Statistical Mechanics (iii) Gravitation	4 + 4

SEMESTER-IV			
Sl No	Course Type	Topic	Credit
1	DSE3 (Theory) (Choose any one out of two options)	(i) Condensed Matter of Physics-I (ii) High Energy Physics-I	4
2	DSE4 (Theory) (Choose any one out of two options)	(i) Condensed Matter of Physics-II (ii) High Energy Physics-II	4
3	DSE5 (Practical) (Choose any one out of two options)	(i) Condensed Matter of Physics Laboratory (ii) High Energy Physics Laboratory	4
4	CORE: 4.1	Project Work	8

SEMESTER-I

Core 1.1 (Theory) **Paper Code: PHSPCOR01T**

Math Methods-50 marks; 4 credit; 60 Lectures

Learning Outcomes:

1. The course of complex variable helps students to apply it in electrical network theory, quantum mechanics etc. Contour integration allows to evaluate improper integrals, which appear in several problems of physics. 2. Studies on matrices provide the basic idea of linear operator, which has wide range of applications in theoretical physics. 3. The course on the vector space helps students to understand Dirac notation in quantum mechanics and also gives the general view of operators. 4. From the course of the ordinary differential equations (ODE) students learn the techniques to solve the ODE which is eventually very important to evaluate the dynamics of many classical and quantum systems.

Mathematical Methods

1. Complex Variables

Function of a complex variable – single and multiple-valued function, limit and continuity. differentiability – Cauchy-Riemann equations and their applications; analytic function – singularity and zero of an analytic function; power series – radius of convergence and circle of convergence; analytic properties of power series, polynomials, exponential function, trigonometric and hyperbolic functions, the function of z; branch point and branch cuts. contours and Riemann's definition of definite integral; estimation of an integral of a complex function along a regular arc, Cauchy's theorem (for simply and multiply connected regions), Cauchy's integral formula for an analytic function (for simply and multiply connected regions) and its derivatives; Taylor's and Laurent expansions; classification of singularities; analytic continuation; residues – Cauchy’s residue theorem, contour integrations, Jordan’s lemma, principal value of an integral. **(12 lectures)**

2. Vector Space and Matrices

Vector space: Axiomatic definition, Linear Independence, Bases, dimension, Inner Product; Schwartz's Inequality, Triangle inequality, Orthogonality of Vectors, Orthonormal Basis, Gram-Schmidt Process of orthogonalization.

Matrices: representation of linear transforms and change of base; similarity, orthogonal and unitarity transformations; independent elements of a matrix; eigen values and eigen vectors; Functions of a matrix; Caley-Hamilton theorem; Commuting matrices; Orthogonality of normal matrices. Hermitian, orthogonal and unitary matrices as special cases of normal matrices. **(13 lectures)**

3. Theory of differential equations

Fuch’s theorem; Linear independence of solutions – Wronskian, secondsolution; Sturm-Liouville theory; Hermitian operators; Completeness, inhomogeneous differential Equations: Green's functions.

Special Functions A general approach starting from the differential equation as well as from the generating function (series expansion for small arguments, recurrence relations, orthogonality relation, etc.) for the Bessel, Legendre, Hermite and Laguerre Functions; Leading term in the asymptotic expansion of Bessel function; Integral representation of Bessel function; Second solution and its singularity (in connection with boundary value problems). **(18 lectures)**

4. Group Theory

Definitions; Multiplication table; Rearrangement theorem; Semi groups; Subgroups–necessary and sufficient condition to be a subgroup; Cosets; Lagrange’s theorem onsubgroups; Conjugate 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; Character of are presentation and orthogonality relations for characters; Construction of charactertables; Decomposition of reducible representations; Application of representation theory in quantum mechanics. **(10 lectures)**

5. Integral Transforms

Fourier and Laplace transforms and their inverse transforms, Bromwich integral (use of partial fractions in calculating the inverse of Laplace transforms); Transform of derivative and integral of a function; Solutions of differential equations using integral transforms. **(7 lectures)**

Core 1.2 (Theory) **Paper Code: PHSPCOR02T**

Classical Mech-50 Marks; 4 credit; 60 Lectures

Learning Outcomes:

1. In this advance level course, our starting point is the Hamilton's principle of least action. Apart from standard application it can provide an alternate description of dynamics in terms of Hamilton-Jacobi theory – doorway to Quantum mechanics. 2. Some special topics, such as O(4) symmetries, symplectic structure of Cannonical transform and Lagrangian formalism of Rigid body dynamics are also included to mastering this subject. 3. Nonlinear dynamics: An active area of modern research. In our curriculum, an exposure to some pivotal results such as KAM theorem and route to Chaos are included.

Classical Mechanics

1. An overview of the Lagrangian formalism

Symmetries of Lagrangian, central force problem, Runge- Lenz vector, stability of circular orbit, small oscillations, normal modes and frequencies. **(6 lectures)**

2. Hamilton's principle

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. **(10 lectures)**

3. Canonical transformations

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 lectures)**

4. Hamilton-Jacobi theory

The Hamilton Jacobi equation for Hamilton's principle function; The harmonic oscillator problem; Hamilton's characteristic function; Action angle variables. **(4 lectures)**

5. Rigid bodies

Inertia tensor and principal axis system; 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. **(12 lectures)**

6. Introduction to Chaos

Stable and unstable fixed points, Linearization, Logistic Map, bifurcation route to chaos. (**6 lectures**)

7. Special theory of relativity

Lorentz transformations; 4-vectors, Tensors, Transformation properties, Metric tensor, Raising and lowering of indices, Contraction, Symmetric and antisymmetric tensors; 4-dimensional velocity and acceleration; 4-momentum and 4-force; Covariant equations ofmotion; Relativistic kinematics (decay and elastic scattering); Lagrangian and Hamiltonian of a relativistic particle. **(12 lectures)**

Core 1.3 (Theory) **Paper Code: PHSPCOR03T**

Quantum Mechanics I -50 Marks; 4 credit; 60 Lectures

Learning Outcomes:

Quantum Mechanics I course is so designed that after the successful completion of the course a student may acquire some expertise Quantum way of thinking. Of courses on quantum mechanics, we thought it reasonable to start from the wave function approach that differential equations as major tools. We concentrate on the operator formalism a la Dirac. A particularly interesting point is to note that, we devote a somewhat more time on the fundamentals of the interpretation, new ideas like guiding waves etc. On the application side our students learn perturbation theory and other approximate methods. So, the outcome of the course is grooming of the students in the structure and essence of the subject.

Quantum Mechanics I

1. Basic principles of quantum mechanics

Heisenberg's uncertainty principle, implications in kinematics, Stern Gerlach Experiment, Principle of superposition of states, illustration by schematic Sequential Stern Gerlach **(6 lectures)**

2. Dirac's formulation of quantum mechanics: the description of states

The bra and ket space; Linear operators; Hermitian and unitary operators; Completeness; Matrix representation, change of basis; Formulation of quantum Description of dynamical statesin bra(c)ket formalism; Observables. Compatible and incompatible observables, quantum mechanically Uncertainty product and Heisenberg's principle. **(8 lectures)**

3. Coordinate and Momentumspace

Coordinate and Momentum, operators; x and p in these representations. Wave functions in position and momentum space. Complete set of commuting observables. Coordinate representation – wave mechanics. wave function, Schrodinger's equation. The time independent Schrodinger's equation. Energy eigen values Stationary states. Scattering states and bound states. **(6 lectures)**

4. Application of wave mechanics

Three dimensional problems in Cartesian coordinates; 3D well and Fermi energy, Angular momentum operators, Spherical harmonics; Radial equation of free particle and three-dimensional harmonic oscillator; Eigenvalue of a 3D harmonic oscillator by series solution. **(8 lectures)**

5. The theory of angular momentum

Representation in terms of coordinates and momentum. The angular momentum algebra. Eigen values of the total angular momentum. The complete set of commuting observables for the angular momentum eigen-kets. Addition of angular momenta. Coupled and uncoupled states, the Clebsch Gordon coefficients. Explicit calculation of the C-G coefficients for the individual angular momenta ½ ½ and ,1/2.,1. **(10 lectures)**

6. Approximate methods

Time independent perturbation theory

First and second order corrections to the energy eigen values; First order corrections to the eigenvectors; Degenerate perturbation theory; Application to one electron system-Relativistic mass correction, Spin-orbit coupling, Zeeman effect and Stark effect. **(8 lectures)**

7. Variation method. Examples. (2 lectures)

8. Helium atom

First order perturbation; Exchange degeneracy; Variational method; Ritz principle for excited states for Helium atom. **(3 lectures)**

9. WKB approximation

The method of WKB approximation, quantization rule, tunneling through a barrier; Qualitative discussion of alpha decay. **(4 lectures)**

10. Measurement and Interpretation

Double Stern-Gerlach experiment for spin-1/2 system; EPR paradox; Idea of quantum entanglement; Hidden variables. Schrodinger "scat; Reduction of wave function; Quantum Xeno effect. **(6 lectures)**

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Core 1.4 (Theory) **Paper Code: PHSPCOR04T**

Electronics & Instrumentation - 50 Marks; 4 credit; 60 Lectures

Learning Outcomes:

After completion the students will get knowledge in 1. Advanced analog electronics 2. Advanced digital electronics and 3. Modern instrumentation. These will also enrich his/her knowledge in practical aspects of the modern physics.

Electronics

1. Power circuits

Series-fed class A power amplifier; Transformer coupled class A power amplifier; Class B power amplifier; Harmonic distortion; Class AB operation, Class C operation. **(4 lectures)**

2. Basic network and filter

Image Impedances, Characteristics impedance, propagation constant, properties of symmetrical network**,** Filter fundamentals; pass and stop bands**,** constant K-low pass, high pass, band pass, band eliminator, active filter, simple examples. **(8 lectures)**

3. Transmission line

Transmission line equation and solution; Reflection and transmission coefficient; Standing wave and standing wave ratio; Line impedance and admittance; Impedance calculation in terms of source impedance and load impedance; Smith chart. **(10 lectures)**

4. Communication principle

Basic principles of amplitude, frequency, phase modulation, frequency spectra of modulated waves, power distribution in AM wave, square law modulator, balanced modulator, average and envelope detection, Double side band suppressed carrier modulation (DSBSC), Single side band modulation (SSB), Coherent detection of DSBSC modulated waves, frequency modulation method and demodulation, narrow band FM, Electromagnetic communication spectrum, Concept of Noise, signal-to-noise (S/N) ratio. Basic ideas of digital communication. Digital modulation techniques: Binary phase shift keying (BPSK), Differential phase shift keying (DPSK), Quadrature phase shift keying (QPSK), M-ARYPSK, frequency shift keying (FSK), M-ARY FSK, amplitude shift keying (ASK). **(12 lectures)**

5. Physics of semiconductor device

Basic semiconductor equations; p-n diode current voltage characteristics; PN diode capacitances; Ebers-Moll equation, hetero junction. **(5 lectures)**

Metal semiconductor junctions: Schottky barriers; Rectifying contacts; Ohmic contacts; Typical Schottky barriers. Characteristics of some semiconductor devices- Tunnel diode, Gunn diode and IMPATT. **(6 lectures)**

6. Digital Circuits

Digital to analog converter (R-2R ladder network, weighted register and modified weighted register), Sample and Hold circuits, quantization & encoding, analog to digital converter (Parallel comparator, successive approximation, dual-slop). **(5 lectures)**

7. Instrumentation

FTIR, UV-Visible spectroscopy, Scanning tunneling microscope, Transmission electron-microscope, Scanning electron microscope. Propagation of errors, Distribution, Least squarefit, Criteria for goodness of fit, Chi-square fit, Binomial distribution, Poisson and normal distribution. Production and measurement of high vacuum: Rotary pump, Diffusion pump, Turbomolecular pump, Ion pump; McLeod gauge, Pirani gauge, Penning gauge. Thin film technology, low temperature Physics. **(10 lectures)**

Gen Expt -50 marks; 4 credit

Learning Outcomes:

Non-Electronics Laboratory

After successful completion of the course students are able to: 1. The Michelson interferometer is a common configuration for optical interferometry. In this expt. beams of light interfered and superimposed. Negative result concludes a great conclusion: That observation confirmed an important prediction of general relativity, validating the theory's prediction of space-time distortion in the context of large-scale cosmic events (known as strong field tests). This inference is the basis of Astro-Physics. 2. From the atomic, molecular and electronic spectra, we study the structure and properties of matter. Lande g-factor is used to study the spectra. 3. Planck's constant (h), a physical constant was introduced by German physicist named Max Planck in 1900. The significance of Planck's constant is that 'quanta' (small packets of energy) can be determined by frequency of radiation and Planck's constant. It describes the behavior of particle and waves at atomic level as well as the particle nature of light. 4. When light shines on a photovoltaic (PV) cell – also called a solar cell – that light may be reflected, absorbed, or pass right through the cell. The PV cell is composed of semiconductor material; the "semi" means that it can conduct electricity better than an insulator but not as well as a good conductor like a metal. There are several different semiconductor materials used in PV cells. Students are able to measure and characterize new cells.

Electronics Laboratory

5. The field-effect transistor (FET) is a type of transistor that uses an electric field to control the flow of current in a semiconductor. ... FETs control the flow of current by the application of a voltage to the gate, which in turn alters the conductivity between the drain and source. 6. A multivibrator is an electronic circuit used to implement a variety of simple two state devices such as relaxation oscillators, timers, and flip-flops. It consists of two amplifying devices (transistors, vacuum tubes, or other devices) cross-coupled by resistors or capacitors. The first multivibrator circuit, the astable multivibrator oscillator, was invented by Henri Abraham and Eugene Bloch during World War I. They called their circuit a "multivibrator" because its output waveform was rich in harmonics. Students could know the function and use of this in IT fields. 7. To demodulate a Frequency Modulated signal using FM detector. Theory: The process, in which the frequency of the carrier is varied in accordance with the instantaneous amplitude of the; modulating signal, is called„ Frequency Modulation‟. Students could know the function and use of this in IT fields.

General Laboratory

Part-A: Electronics

1) Construction of a regulated power supply on a bread board, using (i) a power transistor as pass element (ii) a second transistor as a feedback amplifier and (iii) a zener diode as a reference voltage source and to study its operational characteristics.
2) Construction of active low-pass, high-pass and band-pass filters circuit using OP-AMP.
3) Solution of differential equations using OP-AMP
4) Design and study of multivibrators
5) To design and fabricate a temperature controller and to study its performance characteristics
6) Design and study the ECL OR/NOR logic

Part-B: NON-Electronics

1) Experiments with Michelson Interferometer.
2) Frank – Hertz Experiment.
3) Determination of ‘e’ by Millikan’s oil drop method.
4) Experiments with a G. M. counter.
5) Experiments with Laser and its characteristics.
6) Study of a Photovoltaic Cell.

SEMESTER-II

Core 2.1 (Theory) **Paper Code: PHSPCOR06T**

Electrodynamics - 50 Marks; 4 credit; 60 Lectures

Learning Outcomes:

After successful completion of this course the students will be able to gain knowledge about the following: - 1) Review of the topics pertaining to Electrostatics and Magnetostatics. Electromagnetic induction – Faraday's law. 2) Electromagnetic fields stressing on Maxwell's equations in stationary and moving media; Energy Flow – Poynting vector; Maxwell's stress-tensor for electromagnetic fields; Electromagnetic momentum and Radiation Pressure. 3) Radiation from time-dependent sources of charges and currents – Scalar and Vector Potentials – Gauge invariance of Electrodynamics; Inhomogeneous wave equations and their solutions by Green's function method; Calculation of radiation from various sources; Electric dipole radiation. 4) Radiation from moving point charges – Leinard-Wiechert potentials; Fields from moving charges – uniform velocity, accelerated charge, and relativistic velocity; Bremsstrahlung; Synchrotron radiation; Cherenkov Radiation. 5) Radiation reaction, scattering and dispersion – energy conservation, characteristics of charged harmonic oscillator; scattering of e. m. radiation by free and bound electrons and Kramers-Kronig dispersion relation. 6) Concepts of Relativistic Electrodynamics – E. M. field tensor, covariance of Maxwell's equations; Lorentz transformation law for the e. m. fields; Field invariants and Covariance of Lorentz force equation, Energy-Momentum tensor and the conservation laws for the e. m. field; Relativistic Lagrangian and Hamiltonian of a charged particle in an e. m. field. 7) Fundamentals of Plasma Physics; Individual particle model; Magnetic mirrors; Basic equations and wave propagation – Magnetohydrodynamic approximation; Pinch effect; Plasma Oscillations and Debye length.

Electrodynamics

1. Introduction

Electrostatics and magnetostatics – an overview.; Boundary value problems multipole expansion of (i) scalar potential and energy due to bounded static charge distribution and (ii) vector potential due to bounded stationary current distribution; Electromagnetic Induction–Faraday's law. **(9 lectures)**

2. Electromagnetic fields

Maxwell's equations in stationary and moving media; Energy flow–Poynting vector; Maxwell's stress-tensor for electromagnetic fields; Electromagnetic momentum; Radiation pressure. **(4 lectures)**

3. Radiation from time-dependent sources of charges and currents

Scalar and Vector Potentials – gauge invariance of Electrodynamics; Inhomogeneous wave equations and their solutions by Green's function method; calculation of radiation from (i)monochromatic sources emitting pulses of finite duration and (ii) strictly monochromatic sources – multipole expansion of potentials in the radiation zone; Electric dipole radiation. **(8 lectures)**

4. Relativistic electrodynamics

Electromagnetic field tensor – covariance of Maxwell's equations; Lorentz transformation law for the electromagnetic fields and the fields due to a point charge in uniform motion; Field in variants--$E.B$ and

$E^2–B^2$; Covariance of Lorentz force

equation and the equation of motion of a charged particle in an electromagnetic field; Energy-momentum tensor and the conservation laws for the electromagnetic field; Relativistic Lagrangian and Hamiltonian of a charged particle in an electromagnetic field. **(10 lectures)**

5. Radiation from moving point charges

Lienard-Wiechert potentials; Fields due to a charge moving with uniform velocity; Fields due to an accelerated charge; Radiation at low velocity and corresponding frequency spectrum of the outgoing radiation; Radiation when velocity (relativistic) and acceleration are parallel; Bremsstrahlung; Synchrotron radiation; Cherenkov radiation (qualitative treatment only). **(12 lectures)**

6. Radiation reaction, scattering and dispersion

Radiation reaction from energy conservation; Line breadth and life time of charged harmonic oscillator; Scattering of electromagnetic radiation by free and bound electrons; Radiation reaction as damping term in dispersion; Kramers-Kronig dispersion relation. **(9 lectures)**

7. Plasma physics

Definition of plasma; Individual particle model --motion of plasma particles placed in electric and magnetic field; Magnetic mirrors. Magneto hydrodynamic approximation –Basic equations and wave propagation; Pinch Effect; Plasma Oscillations and Debye length. **(8lectures)**

Core 2.2 (Theory) **Paper Code: PHSPCOR07T**

Quantum Mechanics II - 50 marks; 4 credit; 60 Lectures

Learning Outcomes:

1. The quantum description of transition and scattering – two very important topics are discussed in this course. Symmetry principles is a very power full analysing tool. An Attempt is taken to reveal different aspects of continues and as well as discrete symmetries through several examples 2. Relativistic quantum mechanics – an important tool for spectroscopy, is also included in our curriculum. The property of lorentz co-varience is an essential part of any relativistic theory. Intricate connection to the symmetry principle is also discussed to make the topic more useful

Quantum Mechanics II

1. Time-dependent Perturbation Theory

Time dependent perturbation theory, interaction picture; Constant and harmonic perturbations — Fermi's Golden rule; Sudden and adiabatic approximations. absorption – stimulated emission; the dipole approximation and selection rules. **(10 lectures)**

2. Scattering theory

Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Ramsauer-Townsend effect; Relation between sign of phase shift and attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering - Green's function in scattering theory; Lippman- Schwinger equation; Born approximation. **(15 lectures)**

3. Symmetries in quantum mechanics

Conservation laws and degeneracy associated with symmetries; Continuous symmetries - space and time translations, rotations; Rotation group, homomorphism between SO(3) and SU(2); Explicit matrix representation of generators for $j = 1/2$ and $j = 1$; Rotation matrices; Irreducible spherical tensor operators, Wigner-Eckart theorem; Discrete symmetries - parity and time reversal. **(15 lectures)**

4. Identical Particles

Meaning of identity and consequences; Symmetric and antisymmetric wave functions; Slater determinant; Symmetric and antisymmetric spin wave functions of two identical particles; Collisions of identical particles. **(6 lectures)**

5. Relativistic Quantum Mechanics

Klein-Gordon equation, Feynman-Stückelberg interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; non-relativistic reduction; Helicity and chirality; Properties of γ matrices; Charge conjugation; Normalization and completeness of spinors. **(14 lectures)**

Core 2.3 (Theory) **Paper Code: PHSPCOR08T**

Stat Mech-50 marks; 4 credit; 60 Lectures

Learning Outcomes:

1. Statistical mechanics provides the way to understand physical systems microscopically and also makes correlations with the macroscopic properties. 2. Quantum statistical mechanics helps the students to understand the low temperature behavior of system. 3. From the study of Ising model students get the basic idea of magnetism. 4. Knowledge of statistical physics enormously helps the students in doing research works in many advance branches of physics e.g., condensed matter physics, particle physics.

Statistical Mechanics

1. Introduction

Objective of statistical mechanics, macrostates, microstates, phase space and ensembles. ergodic hypothesis, postulate of equal a-priori probability and equality of ensemble average and time average, Liouville theorem. **(5 lectures)**

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

Thermal interaction – concept of temperature and entropy, $S = K_B ln\,\Omega$, relation for a microcanonical system, nature of probability of finding a particular microstate of a system in thermal equilibrium, mechanical interaction – generalized force, diffusive interaction – chemical potential, counting of microstates of classical ideal gas and classical harmonic oscillator. **(10 lectures)**

3. Canonical ensemble

System in contact with a heat reservoir, partition function, evaluation of thermodynamic functions, energy fluctuation, d-dimensional classical ideal gas in canonical ensemble, virial theorem, Gibbs paradox and the resolution of the paradox. **(6 lectures)**

4. Grand canonical ensemble

System in contact with a particle reservoir, chemical potential, grand canonical partition function and grand potential, fluctuation of particle number. Chemical potential of ideal gas, equivalence of ensembles. **(4 lectures)**

5. Classical non-ideal gas

Mean field theory and Van der Waals equation of state. **(4 lectures)**

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 – BE and FD distributions. **(7 lectures)**

7. Ideal Bose and Fermi gas

Equation of state, Chemical potential of bosons, Bose Einstein condensation- estimation of critical temperature for Bose Einstein condensation, variation of condensate fraction with temperature, examination of pressure, specific heat, free energy and entropy of ideal Bose gas, properties of liquid Helium. **(7 lectures)**

8. Ideal Fermi gas

Equation of state, thermodynamic functions at $T = 0$, Fermi energy, Fermi momentum, Fermi temperature, derivation of Sommerfeld expansion- low temperature behaviour of chemical potential, average energy and specific heat, white dwarf stars and Chandrasekhar limit. **(6 lectures)**

9. Special topic

Ising model – exact solution for one dimensional case, mean field theory of Ising model, evaluation of critical exponents. **(5 lectures)**

10. Non-equilibrium Statistical Mechanics

Irreversible processes, Classical Linear Response Theory, Brownian Motion, Master Equation, Fokker-Planck Equation, Fluctuation-Dissipation Theorem. **(6 lectures)**

Gen Expt - 50 marks; 4 credit

Learning Outcomes:

Non-Electronics

Lasers have made the revolution in the modern optical technologies but there is hardly any efforts to take up the basic understanding of laser Physics via laboratory classes at graduate and undergraduate level. A simple experiment for studying the life time of the upper laser level under lasing condition, the relaxation oscillations, measurement of threshold current and variation of laser power as a function of current in a laser diode is presented. The experiment utilizes the readily available low cost components, a key chain laser and some of the electronics instrument normally available at any undergraduate laboratory of science and engineering department. 2. The purpose of this experiment is to familiarize the student with the Geiger-Mueller counter. This counter is a widely used pulse-counting instrument for X-ray, gammaray, beta-particle and alpha-particle detection. It uses gas amplification, which makes it remarkably sensitive, while the simple construction renders it relatively inexpensive. The experiments that are designed to accomplish this purpose deal with the operating plateau of the Geiger tube, resolving-time corrections, half-life determinations, and the basic nuclear counting principles. 3. Current carried by charges: negative or positive or by both. So it is important to know which charges are responsible in a particular conductor. Students are able to determine the type of carriers i.e. negative or positive by Hall voltage measurement.

Electronics:

4. Active filters have become a mature technology for harmonic and reactive power compensation of single- and three-phase electric AC power networks with high penetration of nonlinear loads. The increased severity of power quality in power networks has attracted the attention of power engineers to develop dynamic and adjustable solutions to the power quality problems in the form of active filters 5. Demodulation is achieved by sampling the AM signal at carrier frequency. Amplitude modulation (AM) is defined as modifying the amplitude of the carrier wave according to the message or information signal. The disadvantage is that large audio amplifier needs to be used to amplify the message signal. 6. The Intel 8085 ("eighty-eighty-five") is an 8-bit microprocessor produced by Intel and introduced in March 1976. It is a software-binary compatible with the more famous Intel 8080 with only two minor instructions added to support its added interrupt and serial input/output features. Students know the function and use of and utility of microprocessor.

General Laboratory

Part-A: Electronics)

1) Designing of modified weighted resistor digital to analog (D/A) converter.

2) Construction and study of analog to digital (A/D) converter

3) Construction and study of decade and other counters

4) Study of amplitude modulation and demodulation

5) Study of frequency modulation and demodulation

6) Programming the 8085 microprocessor

Part-B: Non-electronics

1) Study of Surfaces and Interfaces using Optical Metallurgical Microscopy.
2) Determination of Lande g-factor by ESR Spectroscopy.
3) Experiments with Fibre Optics.
4) Study of a LED.
5) Experiments based on Faraday Effect.
6) Specific Heat Capacity of Solids.

Core 2.5 (Practical) **Paper Code: PHSPCOR10P**

Computer Laboratory - 50 marks; 4 credit; 60 Lectures

(Fortran 90, Python Languages only)

Learning Outcomes:

After successful completion of this course the students will be able to gain knowledge, gain first-hand experience along with problem-solving after learning about the following: - 1. Basics of - Components of a computer, Compiler, Operating Systems, etc. 2. Fundamentals of C Language – Constants and variables; Input and output statements; Reading and writing formats; Arithmetic and logical expressions; Control assignment statements; Build-in functions; Arrays; Loops, Switch operations' usage of break and continue statements; flow charts, Algorithm and programming; Pointers; Structures; Functions; File management; Allocation of memory, etc. Application to physical and real-time problems.

Module 1

Finding roots of a functions by Newton Rapson, Bisection and a Hybrid of them. Applications to polynomials (all roots including complex ones). Transcendental and its combination with other functional forms. **(5 Lectures)**

Module2

Solutions of simultaneous algebraic equations: Gauss elimination with pivoting, Gauss-Siedel and Jacobi. Inversion and Diagonalization of matrix (Jacobi). **(7 Lectures)**

Module3

Interpolation: Lagrange interpolation with equal and unequally spaced data points: Derivation of Newton-Cotes integration formulas with two, three, four, five data points. Composite formulas. First and Second order differentiation formulas. Spline interpolation. **(7 Lectures)**

Module 4

Numerical solution of differential equations: solution of first and second order ODE, Euler and Runge Kutta methods; implementation with predictor corrector. Solution of partial differential equations in two and three independent variables. **(7 Lectures)**

Module 5

Numerical integration: Application of Newton-cotes and Gaussian Quadrature formulas. Integration of tabulated data points, 2D and 3D integration, Monte Carlo method. **(7 Lectures)**

Module 6

Curve fitting: Least square fitting to data points, Linear and nonlinear fit. Polynomial function, exponential, harmonic and combination of them. **(7 Lectures)**

Module 7

Application of Fourier methods: Discrete Fourier transform and Fast Fourier transform of function and tabulated data points. Convolution and correlation. **(7 Lectures)**

[For each module simple codes have to developed]

Module 8

Application to Physical problems: (1) Diffraction Intensity expression by single slit of finite dimension and straight edge. Plotting of data (2) Finding bound state eigen values in QM finite square well problem. (3) To find eigen values and eigenvectors in a double well potential (few states). Plotting of Probability functions (4) Numerical solution of radial Schrodinger equation in a central atomic potential. Verify virial theorem. Plotting of radial probabilities for 1s, 2s, 3s, 2p, 3p and 3d states. (5) To find eigen values and eigen functions for few states for an anharmonic 1D oscillator. Calculation of <r> at finite temperature. (6) Find out numerically the temperature dependence of chemical potential of a non-interacting Bose gas. (7) Phase space averaging of physical quantities: energy of a classical 1D oscillator (8) Numerical solution of Duffing oscillator and plotting of phase portrait in nonlinear dynamics problem (9) Spectrum analysis by FFT of a given tabulated data. Plotting of output (10) Consider a box function, find autocorrelation function. Plotting of output. **(13 Lectures)**

Marks Distribution: LNB-10, Open Viva-10, Expt:30 (Examination hours 4)
(there will be two LNB one for modules 1-7 and other for module 8 only, at least 8 problems have to be done from Module 8)

SEMESTER-III

Core 3.1 (Theory) **Paper Code: PHSPCOR11T**

Atomic, Molecular and Laser Physics -50 marks; 4 credit; 60 Lectures

Learning Outcomes:

1. This course is to some extent an application of Advanced Quantum Mechanical concepts and Point Group Theory. It is designed so that the students get sufficient exposure to scientific knowledge to enter into the research fields such as Chemical Physics Relativistic Quantum Field Theory and Material Science. 2. The topics in this course covers, quite well, the syllabus of all National Level Examinations, like UGC NET, GATE, etc.in the area of Atomic & Molecular Physics. The UG students (2 students) while doing this course paper got interested and performed project work in the area of Atomic and Molecular Physics.

Atomic Physics (24 Lectures)

1. Interaction of radiation with one electron atom

Interaction Hamiltonian in minimum coupling scheme, The first quantization and the semi classical approximation, The electric Dipole approximation and two forms of interaction Hamiltonian, Transition rates: Absorption, emission, spontaneous emission. Derivation of selection rules in electric dipole approximation, magnetic dipole selection rules; Atomic lifetime. **(5 lectures)**

2. Line shape and line width

Time correlation function and spectral Fourier transform; Properties of time correlation functions; Spectral line shape and line width. **(3 lectures)**

3. Relativistic one electron atom: Fine and hyperfine structure

Dirac equation of Hydrogen atom; Separation of angular coordinates in the Dirac Hamiltonian, Radial eigen value equations, energy eigen vales, ,four component ground state wave function(restricted derivations/without derivation); The Pauli equation; Relativistic higher order corrections of energy (with derivation)to non-relativistic one electron atom; Fine structures of the resulting spectra; Quantitative description of Hyperfine structure and isotope shift in one electron atomic spectrum; Selection rules. **(9 lectures)**

4. Many- electron atom

The many electron atomic Hamiltonian; Antisymmetry principle and determinantal wave function; Independent particle model(with special emphasis on Heatom); Central field approximation; The role of central potential on one electron eigen solutions with Hartree approach; Hartree Fock approach (qualitative); Electron states in a central field, configuration, shells and subshells. Description of atom with L-S interaction scheme within central field approximation, Possible terms of a configuration in L-S coupling, equivalent and non-equivalent electrons, Hunds rule; Lande interval rule. jj coupling. splitting of levels in jjcoupling. **(7 lectures)**

Molecular Physics (24 Lectures)

5. Nuclear motion

Separation of electronic and nuclear motions; Born-Oppenheimer separation and approximation; time independent Schrodinger equation for electronic and nuclear motion for diatomic molecule. Morse potential. Harmonic, cubic approximations of the potential and rotation-vibrational energies using first order perturbation method. **(4 lectures)**

6. Microwave spectroscopy

Classification of molecules according to their symmetry properties; Rotational spectrum of diatomic molecules as rigid or non-rigid rotor; Energy levels, selection rules and spectrum; Intensity of the spectral lines; Diatomic molecule assymmetric top. Energy levels. Selection rules. Symmetry properties of rotational levels. **(4 lectures)**

7. Infrared spectroscopy

Vibrating diatomic molecule; Harmonic oscillator approximation; Anharmonicity; Selection rules for harmonic and anharmonic oscillators; intensity of spectral lines; Vibrating rotator; Rotational fine structure of vibration spectrum; P, R branches. The Q Branch. **(4 lectures)**

8. Electronic spectroscopy

Electronic spectra of diatomic molecules; Vibrational coarse-structure of electronic bands; Intensity distribution; Frank-Condon principle; Dissociation and pre-dissociation; Dissociation energy; Rotational fine-structure of electronic bands; P, Q, R branches. Fortrat parabola. Schrodinger equation (electronic part) for $H2+$ molecule. Shapes of molecular orbitals; Pi and sigma bonds; Symmetry; Spectroscopic terms (for diatomics only) **(6 lectures)**

9. Molecular symmetry and Group theory

Point group of diatomic molecules. Character tables for D2h, C2v and C3v pointgroups; Normal coordinates and normal modes; Application of group theory to molecular vibration. **(3 lectures)**

10. Raman effect

Quantum theory; Molecular polarizability; Pure rotational, pure vibrational and vibrational- rotational Raman spectra of diatomic molecules; Intensity alteration in Raman spectra of diatomic molecules; **(3 lectures)**

Laser Physics (12 Lectures)

11. LASER Physics and application

Spontaneous and stimulated emission; Einsteins coefficients; Idea of light amplification; Threshold condition for LASER excitation; Pumping schemes; Pumping mechanism and rate equations.

Three and four-level LASERs. Ruby, carbon dioxide, dye and semiconductor LASERs; Optical resonators; Longitudinal and transverse modes; Mode selection; Q-switching; Mode locking; Monochromaticity; Temporal and spatial coherence; Saturation spectroscopy; Homogeneous and inhomogeneous broadening; Burning and detection of holes in Doppler broadened two-level systems. **(12 lectures)**

References:

(1) Physics of Atoms and Molecules by B.H. Bransden and C.J.Joachain,

(2) Quantum electronics by A. Yariv

(3) Optical electronics by A.K.Ghatak and K. Thyagarajan

Core 3.2 (Theory) **Paper Code: PHSPCOR12T**

Solid State Physics - 50 marks; 4 credit; 60 Lectures

Learning Outcomes:

After successful completion of this course students will be able to: 1. Learn how solid materials could be classified into amorphous and crystallography. Different types of lattice structure; Bravis lattice, symmetry of periodicity. Learn about how properties of matter depend on structure as well as electronic configuration. They also learn how structure of matter could be studied by X-ray. 2. Know how lattice oscillate and influence the properties of the matter. Know about Mono atomic and diatomic lattice vibration, idea about acoustical and optical band of frequency, forbidden zone. 3. Know magnetic properties and type of magnetic properties of matter. Know difference among diamagnetism, paramagnetism and ferromagnetism and few established theories on magnetism. Dielectric properties of matter. Drude's theory of conduction of electron through matter, drift velocity etc. 4. How band theory develope and fruitfully explain most of the properties of matter. know a newly emerged material properties called superconductivity and its application. Critical temperature and critical magnetic field which are responsible for breaking of superconductivity, type-I and Type-II superconductors and BCS theory on superconductivity

Solid State Physics

1. Crystal structure

Reciprocal lattice and Brillouin zone; Bragg and Laue formulation of X-ray diffraction by a crystal; Atomic and crystal structure factors; Experimental methods of X-ray diffraction – Laue, rotating crystal and powder method; Electron and neutron diffraction by crystals (qualitative discussion); Intensity of diffraction maxima; Extinctions due to lattice centering. Poly-crystals, Micro-crystals, Nano-crystals: what is nano crystal, special properties of nano crystal over other crystals, uses in technology and bio-medicine. **(12 lectures)**

2. Band theory of solids

Bloch equation; Empty lattice band; Nearly free electron bands; Band gap; Number of states in a band; Tight binding method; Effective mass of an electron in a band – concept of holes; Classification of metal, semiconductor and insulator; Fermi surface – cyclotron resonance; Boltzmann transport equation – relaxation time approximation, electrical and thermal conductivity. **(7 lectures)**

3. Lattice dynamics

Classical theory of lattice vibration under adiabatic and harmonic approximation; Vibrations of linear monatomic and diatomic lattices, acoustical and optical modes, long wavelength limits; Optical properties of ionic crystal in the infrared region.; Adiabatic approximation (qualitative discussion); Normal modes and phonons; Inelastic scattering of neutron by phonon; Lattice heat capacity, models of Debye and Einstein, comparison with electronic heat capacity; Anharmonic effects in crystals – thermal expansion and thermal conductivity; Mossbauer effect. **(9 lectures)**

4. Dielectric properties of solids

Static dielectric constant – electronic and ionic polarization of molecules, orientational polarization, static dielectric constants of gases; Lorentz internal field; Static dielectric constants of solids; Complex dielectric constant and dielectric losses, relaxation time; Classical theory of electronic polarization and optical absorption; Ferro-electricity -- dipole theory, case of BaTiO3. **(6 lectures)**

5. **Magnetic properties of solids**

Origin of magnetism; Diamagnetism – quantum theory of atomic diamagnetism, Landau diamagnetism (qualitative discussion); Paramagnetism – quantum theory of paramagnetism, case of rare-earth and iron-group ions, crystal field splitting, quenching of orbital angular momentum; Van-Vleck paramagnetism and Pauli paramagnetism; Ferromagnetism – Curie-Weiss law, temperature dependence of saturated magnetization, Heisenberg exchange interaction, ferromagnetic domains; Ferrimagnetism and antiferromagnetism; Neutron scattering and magnetic structures. **(8 lectures)**

6. **Magnetic resonances**

Nuclear magnetic resonance, Bloch equations, longitudinal and transverse relaxation time; Hyperfine field; Electron-spin resonance. **(3 lectures)**

7. **Imperfections in solids and optical properties**

Frenkel and Schottky defects, defects in growth of crystals; The role of dislocations in plastic deformation and crystal growth; Colour centres and photoconductivity; Luminescence and phosphors; Alloys – order-disorder phenomena, Bragg-Williams theory; Extra specific heat in alloys. **(6 lectures)**

8. **Superconductivity**

Phenomenological description of superconductivity – occurrence of superconductivity, destruction of superconductivity by magnetic field, Meissner effect; Type-I and type-II superconductors; London equations; Heat capacity, energy gap and isotope effect; Outlines of the BCS theory; Cooper pair; Flux quantization and Josephson effect: DC & AC Josephson effect; High T_C superconductors (information only). **(9 lectures)**

Core 3.3 (Theory) **Paper Code: PHSPCOR13T**

Nuclear and particle physics - 50 marks; 4 credit; 60 Lectures

Learning Outcomes:

After completion of the course the students will be able to: 1. get the advanced knowledge in nuclear and particle physics. Nuclear physics is important not only to understand basic physics but also to know the physics behind radiation treatments used in medical oncology. Particle physics is important to appreciate the standard model, which is the basic theory behind the three fundamental forces of the Universe. 2. Study of nuclear radiation detector helps one to understand nuclear radiations namely -rays. Besides, it also gives knowledge about the detector thatγ particles and βα, could be used to contain a particular radiation. 3. The study of detectors as well as nuclear radiation is important in medical physics also, especially for oncological purposes. Therefore, this topic has immense importance in human life. 4. Nuclear reaction gives knowledge in the development of nuclear physics experiments as well as concerned theories. 5. The study of nuclear astrophysics and reactions helps a student to understand how our universe is created, as described in the existing theories. The existence of elements in the earth can also be perceived with the help of nuclear astrophysics. 6. The study of nuclear reaction, especially the fission and fusion, gives knowledge how human society can use science for good as well as evil purposes i.e for the benefit or destruction of the society. 7. Knowledge in particle physics is highly important in today's era when a large number of countries are trying to unfold the mysteries behind the creation of universe through experiments using Large Hadron Collider (LHC) at CERN, Europe. Besides, from the standpoint of career, the topic has immense importance too.

Nuclear and particle 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. Angular momentum, parity and symmetry, Magnetic dipole moment and electric quadrupole moment, experimental determination, Rabi's method. **(4 lectures)**

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. **(3 lectures)**

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. **(6 lectures)**

4. Nuclear structure

Fermi gas model, Shell model (Extreme Single particle, Single particle, and Independent Particle Shell Models), Collective model, Nilsson model. **(8 lectures)**

5. Nuclear reactions

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. **(11 lectures)**

6. β-decay and weak interaction

Energetics of various βdecays, V-A theory of allowed β-decay, Selection rules for Fermi and Gamow-Teller transitions, Parity non-conservation and Wu's experiment, India-based Neutrino Observatory (INO) project: qualitative idea. 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. **(9 lectures)**

8. 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. **(8 lectures)**

9. Electroweak theory

Elementary ideas of electroweak unification and Standard Model. **(2 lectures)**

10. Experimental Techniques in Nuclear physics

Interactions of Heavy charged particles and matter during their passage through materials. Interaction of gamma with matter. **(6 lectures)**

11. Big bang nucleosynthesis

Qualitative idea of BBN, relative abundances of hydrogen, helium, and deuterium. **(3 lectures)**

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

ELECTIVE PAPERS (SEMESTER-III)

(Out of the choice of three electives below, two will be taken by a student)

DSE 1 (Theory) **Paper Code: PHSPDSE01T**

Materials Physics -50 marks; 4 credit; 60 Lectures

Materials Physics:

1. **Introduction & Preliminary Concepts (2 lectures)**

2. **Equilibrium & Kinetics**

Stable and Metastable configurations, Fundamental Thermodynamical Functions, Thermal and Statistical Entropy, Kinetics of Thermally activated processes. **(5 lectures)**

3. **Density Functional Theory (DFT)**

Basics of DFT, Comparison with conventional wave function approach, Hohenberg-Kohn Theorem; Kohn-Sham Equation; Thomas-Fermi approximation and beyond; Practical DFT in a Many-Body calculation and its reliability. **(10 lectures)**

4. **Some Aspects of Preparation & Characterization of Materials**

Crystal Growth & Sintering Process, Major & Minor Phases, Characterization of Bulk & Surfaces, Monocrystals & Polycrystalline compounds, Different types of materials (conductor, insulators, Glasses, Ceramics, etc.) and their preparation. **(12 lectures)**

5. **Physics of Thin Films**

Methods of Film preparation, Various Methods to Examine Films, Growth & Structure of Films, Mechanical Properties of Films, Optical Properties of Films, Electrical Properties of Films and Magnetic Properties of Films. **(12 lectures)**

6. **Introduction to Nano-materials**

Basics of Nano-particles (metals and other compounds), Nano-clusters, and Nano-tubes; Porous Silicon; Physical Techniques to Fabricate Nano-structures; Introduction to Nano-technology. **(14 lectures)**

7. **Elementary Bio-compounds**

Introduction to bio-compounds, their Classification; Carbon and related compounds; Recent organic compounds for Opto-electronic devices and their applications. **(5 lectures)**

Statistical Mechanics - 50 marks; 4 credit; 60 Lectures

Statistical Mechanics

1. Classical Ising model (14)

Definition of the Ising model, application to binary alloy and lattice gas, two dimensional Ising model under zero external field: high and low temperature expansion, expression for critical temperature by duality transformation, Kinetic Ising model: stochastic Dynamics, relaxation, critical dynamics (introduction only), single spin-flip Glauber model; conserved Ising model-Kawasaki dynamics. **(14 lectures)**

2. Principles of computer simulations

Monte Carlo technique-simple sampling and importance sampling, Monte Carlo algorithms for random walk and Ising model. **(4 lectures)**

3. Quantum Ising Model

Introduction to transverse field Ising model, duality transformation, exact solution for one dimensional transverse filed Ising model. **(6 lectures)**

4. Phase transitions and critical phenomena

Basic themes, liquid-gas and uniaxial ferromagnetic phase transitions, first order and continuous phase transitions and critical points, behaviour of thermodynamic functions near the critical point, convexity properties, critical exponents, concept of universality.

Landau theory of phase transitions, evaluation of critical exponents, beyond mean field theory, Landau-Ginzburg Hamiltonian, Gaussian expansion for $T > T_c$ and $T < T_c$, concept of correlation length and its temperature dependence.

Scaling hypothesis, scaling dimension, scale transformation and dimensional analysis, scaling and hyperscaling relations of critical exponents, critical phenomena in finite systems: finite size scaling ansatz.

Block Hamiltonian and Kadanoff transformation, Renormalisation group: Real space renormalisation group (RSRG): motivation, definition of RG, recursion relations and fixed point, relevant, irrelevant and marginal parameters, flow diagrams, scaling field, critical exponent. **(25 lectures)**

5. Real gas

Equation of State, Mayer-Ursell cluster expansion. **(3 lectures)**

6. Applications in Quantum Statistical Mechanics

Super fluidity, thermionic effect of electrons, photoelectric effect, Pauli paramagnetism **(8 lectures)**

Gravitation -50 marks; 4 credit; 60 Lectures

Gravitation

1. Special Relativity and Lorentz transformations

Algbraic approach and geometric approach, Lorentz contraction of length, time dilations derived Motion in space time, the invariant interval, metric, Minkowski space, Flat space-time. **(4 lectures)**

2. The Equivalence Principle

Weak and strong form. Gravity and curvature of spacetime, General coordinate transformations and the diffeomorphism invariance. Significance of the general covariance of physical laws. **(2 lectures)**

3. Geometrical Basis (25)

Contravariant and covariant vectors; Tangent vectors and 1-forms; Tensors: product, contraction and quotient laws; Wedge product, closed forms; Levi-Civita symbol; Tensor densities, the invariant volume element. Parallel transport and the affine connection; Covariant derivatives; Metric tensor, raising and lowering of indices; Christoffel connection on a Riemannian space; Geodesics; Space-time curvature; Curvature tensor; Commutator and Lie derivative; Equation for geodesic deviation; physical connection with the example of expanding universe **(25 lectures)**

4. General Theory of relativity

Einstein's equations, a digression on relativistic fluids, Lagrangian formulation, The Einstein – Hilbert action, treatment of the boundary values (qualitative discussion). **(8 lectures)**

5. Applications of General relativity

(a) The Swarzschild solution:

The Schwarzschild Metric, singularities, Geodesics of the Schwarzschild solution Experimental Tests of General Relativity, Schwarzschild Black holes. Charged cbloack holes – Reissner Nordstorm Black holes, Rotating solutions – Kerr black holes, Black hole thermodynamics. **(15 lectures)**

6. Research on Gravitation – an overview. **(6 lectures)**

SEMESTER-IV

DSE4 (Theory) **Paper Code: PHSPDSE04T**

CMP Advance-1-50 marks; 4 credit; 60 Lectures

1. Fundamentals of many-electron system (13)

Hartree-Fock theory (12) The basic Hamiltonian in a solid – electronic and ionic parts, the adiabatic approximation; Single- particle approximation of the many-electron system – single product and determinantal wave functions, matrix elements of one and two-particle operators; The Hartree-Fock (H-F) theory – the H- F equation, exchange interaction and exchange hole, Koopmans theorem; The occupation number representation,: the many electron Hamiltonian in occupation number representation; Wick's theorem and it's application: The Fock operator, the H-F ground state energy.

2. The interacting free-electron gas: Quasi electrons and Plasmon (18)

The Schrodinger equation in First and second quantization: The Hamiltonian of metallic free electron gas in second quantisation, The H-F approximation of the free electron gas-exchange hole, single-particle energy levels, the ground state energy; Perturbation theoretic calculation of the ground state energy; Correlation energy – difficulty with the second order perturbation theoretic calculation, Wigner's result at high density, low density limit and Wigner interpolation formula; Cohesive energy in metals; Screening and Plasmons; Experimental observation of plasmons; The dielectric function of the electron gas; Friedel oscillation; Quasi-electrons; Landau's quasi-particle theory of Fermi liquid; Strongly correlated electron gas; Mott transition.

3. Spin-spin interaction: Magnons (8)

The exchange interaction; Direct exchange, super exchange, indirect exchange and itinerant exchange; Spin-waves in ferromagnets – magnons, spontaneous magnetization, thermodynamics of magnons; Ferromagnetic domains, anisotropy energy and Bloch wall; Spin-waves in lattices with a basis – ferri- and anti-ferromagnetism; Ordered magnetism of valence and conduction electrons, the collective electron model; Kondo effect; Measurement of magnon spectrum.

4. Superconductivity (8)

Electron-electron interaction via lattice – Cooper pairs; BCS theory; Ginzburg-Landau theory and London equation; Meissner effect; Type II superconductors – characteristic length; Josephson effect; "Novel High Temperature" superconductors.

5. Disordered systems (13)

Disorder in condensed matter – substitutional, positional and topographical disorder; Short and long range order; Atomic correlation function and structural descriptions of glasses and liquids; Anderson model for random systems and electron localization; mobility edge; Qualitative application of the idea to amorphous semiconductors and hopping conduction.

High Energy Physics-I, 50 marks; 4 credit; 60 Lectures

1. Introduction (4):

Necessity of field viewpoint; Classical fields: Euler – Lagrange equations; Symmetry transformations: Noether's theorem, Space-time and internal symmetries.

2. Lorentz group (10):

Lorentz transformations: continuous and discrete, proper and improper; Group structure, representations (scalar, vector, tensor, spinor, etc.), SL(2,C) representations, bilinear covariants ,trace relations; Chirality and Helicity; Chiral symmetry-Noether currents, PCAC, Poincare group.

3. Canonical quantization of free fields (10):

Real and complex scalar fields, Dirac field; Propagators; Discrete transformations (Parity, Time reversal and Charge conjugation) on scalar, Dirac and electromagnetic fields.

4. Interacting fields (6):

Interaction picture, covariant perturbation theory, S-matrix, Wick's theorem; Feynman diagrams and rules.

5. Particle physics preliminaries (4):

Relativistic kinematics; Mandelstam variables and use of crossing symmetry; Decay rates and scattering cross-sections.

6. Quantum electrodynamics (6):

Feynman rules; Examples of actual calculations chosen from Rutherford, Bhabha, Moller or Compton scattering and $e^+ e^- \rightarrow \mu^+ \mu^-$

7. Introduction to functional methods (6):

Path integral in quantum mechanics, functional derivatives, generating functional, Scalar field theory in functional form; Functional approach to gauge theories- quantization of electromagnetic field.

8. Higher order corrections (6):

One loop diagrams, degree of divergence, basic idea of regularization and renormalization; Calculation of self-energy of scalar phi-fourth theory using cut-off or dimensional regularization.

9. Hadron Structure (8):

Elastic e-p scattering, electromagnetic form-factors, electron–hadron deep inelastic scattering, structure functions, scaling, sum rules, neutrino production.

CMP Advance-2-50 marks; 4 credit; 60 Lectures

1. Symmetry in crystals (10)

Concepts of point group; Point groups and Bravais lattices; crystal symmetry – space groups; Experimental determination of space groups; Symmetry and degeneracy - crystal field splitting; Kramer's degeneracy; Quasi-crystals – general idea; approximate translational and rotational symmetry of two-dimensional Penrose tiling; Frank-Casper phase in metallic glass.

2. Lattice dynamics (14)

Classical theory of lattice vibrations in 3-dimensions under harmonic approximation; dispersion relation – acoustical and optical, transverse and longitudinal modes; lattice vibrations in a monatomic simple cubic lattice; frequency distribution function; normal coordinates and phonons; occupation number representation of the lattice Hamiltonian; thermodynamics of phonons; the long wavelength limits of the acoustical and optical branches; neutron diffraction by lattice vibrations; Debye-Waller factor; atomic displacement and melting point; phonon-phonon interaction; interaction Hamiltonian in the occupation number representation; thermal conductivity in insulators.

3. Electron states (16)

Derivation of Bloch's theorem in 1D; Motion of electron in 1D lattice: symmetry of the reciprocal lattice; weak periodic crystal potential; representation of bands in different schemes; Energy gaps and Bragg's reflection; Derivation of k versus E(k) relation with Tight binding method; generalization to 3D lattice; Symmetry properties of the energy function. Other band calculation methods: Celular method (atomic sphere approximation); Augmented plane wave; orthogonalized plane wave and the pseudo potential method; density of states; principles of photo electron spectroscopy.

4. Electronic properties-I (10)

Motion of electrons in bands and the effective mass; currents in bands and holes; scattering of electrons; the Boltzmann transport equation and relaxation time; electrical conductivity of metals – scattering due to impurities; resistance at high and low temperatures; U-processes; thermoelectric effects; thermal conductivity; the Wiedemann Franz law; phonon drag.

5. Electronic properties-II (10)

Electronic properties in a magnetic field; classical theory of magneto-resistance; Hall effect and magneto-resistance in the two band model; k-space analysis of electron motion in a uniform magneticfield; idea of closed, open and extended orbit; cyclotron resonance; other types of resonance; energylevels and density of states in a magnetic field; Landau diamagnetism; de Hass-van Alphen effect; quantum Hall effect;magnetic breakdown.

High Energy Physics -2-50 marks; 4 credit; 60 Lectures

1. Lie groups (8):

Groups, algebras and representations; Orthogonal and unitary groups. Particular emphasis on U(1), SU(2) and SU(3) groups; Root and Weight diagrams ; Young tableaus.

2. Gauge Theories (6):

Global and local symmetries-Noether currents; U(1) gauge invariance ;Geometric interpretation of gauge invariance, Yang-Mills theory.

3. Quark model (6):

Isospin and hypercharge: hadron multiplets as global SU(2) and SU(3) representations, Quark model; Invocation of colour; Heavy quarks and their hadrons

4. Strong Interactions (5):

Quantum chromodynamics, asymptotic freedom, Gluons and jets $e^+ e^- \rightarrow$ hadrons, scaling violation.

5. Low energy weak interactions (5):

Fermi theory, calculations of decay width of muon and charged pion.

6. Spontaneous Symmetry breaking (8):

Different types of symmetry breaking; Spontaneous breakdown of discrete and continuous symmetries, Goldstone boson, Higgs mechanism.

7. Electro-weak theory (10):

The symmetry group and its spontaneous breakdown, gauge boson and fermion masses, neutral current, experimental tests; Calculation of FB asymmetry in $e^+ e^- \rightarrow \mu^+ \mu^-$ and decay widths of W and Z bosons (only at tree-level); Higgs physics; Reasons for looking beyond the electroweak theory.

8. Flavour physics (5):

Quark mixing, absence of tree-level FCNC in Standard model, the CKM matrix, oscillation in K and B systems, CP violation.

9. Neutrino physics (5):

Theory of two-flavour oscillation. Solar and atmospheric neutrino anomalies. Neutrino experiments.

10. High Energy Physics Experiments (2) :

Relative merits and demerits of $e^+ e^-$ and hadronic colliders, LEP, LHC and B-factories.

CMP – Advance II - Special Lab – 50 Marks, 4 credit

1) Experiments based on X-ray Crystallography.

2) Differential Scanning Calorimeter (DSC) based experiments.

3) UV-VIS Spectroscopic Experiments to determine absorption coefficients and Optical Band Gap.

4) Fourier Transform Infrared (FTIR) Spectroscopy

5) Thin Film Deposition and Measurement of conductivity – 4 Probe Method.

6) Ellipsometer Experiments to Determine refractive index (n) & Extinction Coefficient (k) of material.

7) Measurement of the band-gap of a semiconductor by the four-probe method

8) Dispersion relations in periodic electrical circuits – Study of the electrical analogues of monatomic and diatomic chains

9) Measurement of dielectric constant

10) Study of magneto-resistance and Hall effect at different temperatures

11) Measurement of magnetic susceptibility of $FeCl_3$ /$MnSO_4$ by Quincke's method

DSE9 (Practical) **Paper Code: PHSPDSE09P**

High Energy Physics II - Special Lab – 50 Marks, 4 credit

1. Experiments with GM counter:

(a) Drawing of absorption curves for beta particles emitting RaD, Sr^{90}-Y^{90} and Ti^{204} where aluminium is used as the absorber and hence determine the range of beta's using Feather's analysis. Using range–energy relation gives an estimate of kinetic energies of beta particles.

(b) Determination of mass absorption coefficients (of Al and Pb) for the gamma ray emitting from Co^{90} and give an estimate of the energy of gamma ray.

2. Experiment with Scintillation counter and SCA

Identification of photo-peaks of observed gamma energy distribution for given gamma sources and hence draw the calibration curve and estimate the resolving power of photo-peak efficiency of the detector. Using calibration curves determine the energy of photo peak(s) for unknown gamma source.

3. Experiment with Solid state detector

(a) Measurement of the stopping power of air for alpha particle emitting from ${}_{95}Am^{241}$ by using ADC and multi-channel analyser and hence determine the range and energy of emitting alpha.

(b) Determination of life time of μ-meson by designing coincidence experiment.

Core 4.1 (Project) Paper **Code: PHSPCOR14M**

Project-100 Marks; 8 credit; 100 Lectures