Office of the Vice-Chancellor
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COOCHBEHAR PANCHANAN BARMA UNIVERSITY

PHYSICS

PG (NCCF) syllabus

Course Structure and Syllabus for M. Sc in Physics

as per

National Education Policy (NEP 2020)

With effect from academic session 2026-27 and onwards)

A Four Semesters Course

28/07/2026 28/07/26 28.07.2026

COOCH BEHAR

WEST BENGAL

28/7/2026 Forward to The Dean of Science 4/8/26

placed before the Hon'ble Vice-Chancellor for necessary approval. 28.07.2026

Dean Faculty of Post-Graduate Studies in Science, Technology & Vocational Studies, Cooch Behar Panchanan Barma University

PHYSICS PG (NCCF) CURRICULUM

M.Sc. in Physics

- **This is a four semester programme course.**
- **The Curriculum consists of six Core Courses (Core 1-6), one Discipline Centric Elective (DCE) Course, one Generic Elective (GE) Course, three Coursework Papers (CP1-3) and Five Research papers (RP1-5).**
- **Students after completing four year NCCF Undergraduate programme will take Semester III and Semester IV courses only.***
- **Students after completing three year NCCF Undergraduate programme will take Semester I, II, III and IV courses.**

* One year (3rd to 4th Semester of this Syllabus to be treated as 1st and 2nd Semester)

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Course Structure

Semester	CORE COURSE (6)	Discipline Centric Elective DCE (1)	Generic Elective (1)	Course Work Paper CP(3)	Research Paper (5)
I	Core-1 (5 credit) Core-2 (5 credit) Core-3 (5 credit)	DCE (5 credit)			
II	Core-4 (5 credit) Core-5 (5 credit) Core-6 (5 credit)		GE (5 credit)		
III				CP-1 (5 credit) CP-2 (5 credit) CP-3 (5 credit)	RP-1 (5 credit)
IV					RP -2 (5 credit) RP-3 (5 credit) RP-4 (5 credit) RP-5 (5 credit)

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Course details

SEMESTER	COURSE OPTED	COURSE NAME	Credits
I	Core Course-1	Mathematical Methods in Physics -I	5
	Core Course-2	Classical Mechanics	5
	Core Course-3	Quantum Mechanics –I	5
	Discipline Centric Elective (DCE)	Electronics + Laboratory Course I	5
II	Core Course-4	Mathematical Methods in Physics -II	5
	Core Course-5	Statistical Mechanics	5
	Core Course-6	Atomic and Molecular Physics	5
	Generic Elective (GE)	Solid State Physics	5
III	Course Work Paper (CP)	Quantum Mechanics –II and Relativistic Kinematics	5
	Course Work Paper (CP)	Nuclear and Particle Physics	5
	Course Work Paper (CP)	Electrodynamics and plasma physics	5
	Research Paper (RP) I	Research Methodology and Project-I (Literature Review on a specific topic as prescribed by the supervisor)	5
IV	Research Paper (RP) -II	Astrophysics and Cosmology-I/Nuclear Physics and Particle Physics I//Solid State Physics I (**one course from the cluster**)	5
	Research Paper (RP)-III	Astrophysics and Cosmology-II/Nuclear Physics and Particle Physics II//Solid State Physics II (**one course from the cluster**)	5
	Research Paper (RP)-IV	Astrophysics and Cosmology-II/Nuclear Physics and Particle Physics III/Solid State Physics III (**one course from the cluster**)	5
	Research Paper (RP) -V	Project-II (Final submission of the project and dissertation)	5
Total Credits			80

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Semester wise distribution of Marks

Semester-I

Sl. No.	Paper	Marks	Continuous evaluation	Attendance	Total	Credit
1.	Core-1	75	20	05	100	05
2.	Core-2	75	20	05	100	05
3.	Core-3	75	20	05	100	05
4	DCE	Theory:50 + Lab: 25	10+10	05	100	05

Semester-II

Sl. No.	Paper	Marks	Continuous evaluation	Attendance	Total	Credit
1.	Core-4	Theory: 75	20	05	100	05
2.	Core-5	Theory: 75	20	05	100	05
3.	Core-6	Theory: 75	20	05	100	05
4.	GE	Theory:50 + Lab: 25	10+10	05	100	05

Semester-III

Sl. No.	Paper	Marks	Continuous evaluation	Attendance	Total	Credit
1.	CP-1	Theory: 75	20	05	100	05
2.	CP-2	Theory: 75	20	05	100	05
3.	CP-3	Theory: 75	20	05	100	05
4.	RP-1	Theory: 50 Project-Stage I: 25	20	05	100	05

Semester-IV

Sl. No.	Paper	Marks	Continuous evaluation	Attendance	Total	Credit
1.	RP-2	75	20	05	100	05
2.	RP-3	75	20	05	100	05
3.	RP-4	Theory: 50 Lab: 25	20	05	100	05
4.	RP-5	Project-Stage: II presentation: 50 Evaluation of the project report: 25	Academia/ Industry Visit 20 Marks	05	100	05

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Semester-I

Core -1: Mathematical Methods in Physics-I

Unit-I: COMPLEX ANALYSIS

Complex Variables, Limits, Continuity, Derivatives, Cauchy-Riemann Equations, Analytic functions, Harmonic functions, Elementary functions: Exponential and Trigonometric, Taylor and Laurent series, Residues, Residue theorem, Principal part of the functions, Residues at poles, zeroes and poles of order m, Contour Integrals, Evaluation of improper real integrals, improper integral involving Sines and Cosines, Definite integrals involving sine and cosine functions.

Unit-II: MATRICES

Matrices, Eigenvalues and Eigen vectors, orthogonal, unitary and Hermitian matrices, Diagonalization of Matrices, Application to Physics problems. Functions of matrices. Powers of a matrix. Roots of a matrix. Exponential of a matrix, Logarithm of a matrix.

Unit-III: PARTIAL DIFFERENTIAL EQUATIONS AND INTEGRAL TRANSFORMS:

Fourier transforms. Inverse Fourier transforms. Fourier transform of derivatives. Convolution theorem. Momentum representation. Laplace transforms. Inverse Laplace transforms. Laplace transform of derivatives. Derivative of a transform. Integration of transforms. Laplace Convolution theorem. Solution of ordinary and partial differential equations by Fourier and Laplace transform methods.

Unit-IV: DIFFERENTIAL EQUATIONS AND SPECIAL FUNCTIONS:

Legendre, Bessel and Hermite differential equations. Dirac's delta function; Gamma and Beta functions; Legendre and associated Legendre polynomials.

Main References:

1. ***S. D. Joglekar, Mathematical Physics: The Basics, Universities Press 2005.***
2. ***S. D. Joglekar, Mathematical Physics: Advanced Topics, CRC Press 2007.***
3. ***M.L. Boas, Mathematical methods in the Physical Sciences, Wiley India 2006.***
4. ***G. Arfken and H. J. Weber: Mathematical Methods for Physicists, Academic Press 2005.***

Additional References:

1. ***A.K. Ghatak, I.C. Goyal and S.J. Chua, Mathematical Physics, McMillan.***
2. ***A.C. Bajpai, L.R. Mustoe and D. Walker, Advanced Engineering Mathematics, John Wiley.***
3. ***E. Butkov, Mathematical Methods, Addison-Wesley.***
4. ***J. Mathews and R.L. Walker, Mathematical Methods of physics.***

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5. *P. Dennery and A. Krzywicki , Mathematics for physicists.*
6. *T. Das and S.K. Sharma, Mathematical methods in Classical and Quantum Mechanics.*
7. *R. V. Churchill and J.W. Brown, Complex variables and applications, V Ed. Mc Graw. Hill.*
8. *W. Joshi, Matrices and Tensors in Physics, Wiley India.*

Core -2: Classical Mechanics

Unit-I: LAGRANGE'S AND HAMILTON'S PRINCIPLE:

Principle of virtual work and D' Alembert's principle; constraints, generalized coordinates and Lagrange's equation of motion. Elements of calculus of variation, applications; Hamilton's principle; principle of least action; Lagrange's equations for non-holonomic and dissipative systems; generalized momenta; phase space and configuration space; symmetry and conservation theorems.

Unit-II: HAMILTON'S EQUATIONS:

Legendre transformation and derivation of Hamilton's canonical equations; derivation of canonical equations from a Variational principle; Routhian and Routh's procedure.

Unit-III: CANONICAL TRANSFORMATIONS:

Equation of canonical transformation, generating functions, Lagrange and Poisson brackets (PB); canonical invariance of Poisson brackets; equation of motion in PB notation; infinitesimal canonical transformation and constants of motion, angular momentum PB relations; Liouville's theorem.

Unit-IV: HAMILTON JACOBI THEORY:

H-J equation, separation of variables; Hamilton's principal and characteristic functions; action angle variables.

Unit-V: RIGID BODY DYNAMICS:

Kinematics of rigid body motion; degrees of freedom; Euler angles; The Cayley-Klein parameters and spinors; infinitesimal rotation and pseudo vector; rotating frame and pseudo forces; torque free motion of a rigid body; heavy symmetrical top.

Unit-VI: SMALL OSCILLATIONS:

Stable and unstable equilibria; small oscillations; the Eigen value equation and the principal axis transformation for oscillatory systems; frequencies of free vibration and normal co-ordinates; vibration of linear triatomic molecule.

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Unit-VII: CONTINUOUS SYSTEM AND FIELDS:

Lagrangian and Hamiltonian formulation for continuous systems, symmetry and conservation principles, Noether's theorem, classical field theory.

Unit-VIII: INTRODUCTION TO AUTONOMOUS SYSTEMS:

Non-linear systems, Lyapunov exponents, Basic idea of chaos.

References:

1. ***Classical mechanics-Goldstein***
2. ***Introduction to advances dynamics-McCuskey***
3. ***Mechanics- Landau and Liftshitz.***
4. ***Classical Mechanics- K.C. Gupta***
5. ***Classical Mechanics- Rana and Jog***
6. ***Relativity-R Resnick***

Core-03: Quantum Mechanics I

Unit-I: GENERAL FORMALISM:

States, observables and operators in quantum mechanics, Dirac's notation, measurement, co-ordinate and momentum representation. Schrodinger, Heisenberg and interaction picture, Heisenberg's equation of motion.

Unit-II: EIGENVALUE PROBLEMS:

Matrix method: Dirac notation for quantum state, linear harmonic oscillator, angular momentum, Pauli's spin-1/2 matrices.

Unit-III: APPROXIMATION METHODS:

Time independent perturbation theory - non-degenerate and degenerate cases, application to one-electron atom. Time dependent perturbation theory, transition probability, Fermi's golden rule, application of time dependent perturbation theory. WKB method, quantization rule, connection formula, application to tunneling through a barrier. Variational method, application to H and He-atom, Ritz principle for excited states.

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Unit-IV: SYMMETRIES:

Symmetries and conservation laws in quantum Mechanics, continuous symmetries, space and time translation, rotation, rotation groups, infinitesimal transformation and Lie groups, Wigner-Eckart theorem, discrete symmetries, parity and time reversal.

Unit-V: ANGULAR MOMENTUM:

Orbital and spin angular momenta, spin matrices and spinors. Addition of angular momenta, Clebsch-Gordon coefficients.

References:

1. ***Quantum Physics by Robert Eisberg and Robert Resnick (John Wiley and sons).***
2. ***Quantum Theory by D. Bohm (Prentice-Hall).***
3. ***Quantum Mechanics: Theory and Applications by A. K. Ghatak and d S. Lokanathan (Macmillan India Ltd.).***
4. ***Quantum Mechanics by L. I. Schiff (McGraw-Hill Book, New York).***
5. ***Quantum Mechanics by Cohen and Tanaudji.***
6. ***Quantum mechanics by Prabir Ghosh, Narosa Publication***

DCE : Electronics (Theory +Lab)

Unit-I: BASIC SMALL SIGNAL AMPLIFIERS:

Classification of amplifiers, BJT/FET amplifier circuits, model and generalized amplifier circuits, Bootstrapped and Darlington amplifier circuit. Cascade amplifiers, Difference amplifiers, Multistage R-C coupled amplifiers. Noise in electronic circuits.

Unit-II: FEEDBACK IN AMPLIFIERS:

General properties of feedback amplifiers, types of feedback and their effect on impedance levels. Practical feedback amplifiers using BJT, FET and OP-AMP. Audio power amplifiers. Audio power amplifier requirements, Class A, Class B and Class C power amplifiers, Push pull and tuned power amplifiers.

Unit-III: OSCILLATORS:

Feedback sinusoidal oscillator and condition of oscillation, Phase-shift oscillator, Wien bridge oscillator and Multivibrator using BJT / FET; Differential amplifiers, DC and AC analysis, CMRR, constant current bias level translator.

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Unit-IV: OP-AMP AND ITS APPLICATIONS:

Input offset voltage and current, input bias current, total output offset voltage, CMRR and frequency response. Mathematical Operations: DC and AC amplifier, circuits for summing, scaling, integrator and differentiator, log, antilog and other mathematical operations. Solution of second-order differential equations, Comparators, square wave and triangle wave generators, voltage regulators, fixed and adjustable voltage regulators, switching regulators, active filters.

Unit-V FLIP FLOPS:

RS latches, level clocking, edge-triggered D flip flops, edge-triggered JK flip flops, JK master-slave flip flops. Excitation table of flip-flops.

Unit-VII: COMBINATIONAL LOGIC DESIGN:

Standard representation for logical functions, Karnaugh map representation of logical functions, simplification of logical functions using K-map, minimization of logical functions specified in Minterms/Maxterms or truth table, Don't care conditions, X-OR and X-NOR simplification of K-maps, five and six variable K-maps.

Unit-VIII: NETWORKS AND LINES:

Mesh and node analysis, network impedances, network theorems. Resonant circuits, inductively coupled circuits, reflected impedance. Passive filter circuits.

Unit-IX: WAVEGUIDE:

Wave guides and resonant cavities: Basic concept of wave guides, TE & TM modes, Rectangular waveguide, circular waveguide, resonant cavities, rectangular cavity resonator-TE, TM modes. Power loss in a cavity. Q factor of a cavity.

Lab:

(List of experiments should be regarded as suggestive of the standard and may not be strictly adhered to. New experiments of similar standard may be added and old experiments may be deleted whenever felt it necessary).

a. To design and construct a stabilized power supply (Constant Voltage Source) using discrete devices and to study the variation of load voltage with load current. Show also the variation of load voltage with load current using IC 78XX.

b. To design and construct constant – K type (a) low pass (b) high pass (c) band pass filters and to study the variation of attenuation and phase constants of these filters with input frequency. To determine the cut off frequencies and to compare with theoretical values.

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c. To study the variation of output voltage with frequency and load resistance for a given class-B Push Pull amplifier and to obtain the variation of output power with frequency and load resistance.

d. To design and construct clipping and clamping circuits using diodes and to study the variation of output amplitude and wave form using CRO.

e. To design an astable multivibrator using BJT and to study its output waveform and frequency for various RC values. To study how the output can be converted to a square wave using clipping circuit.

f. To design a Uni-junction Transistor circuit and draw its characteristic curves for different values of supply voltage. Use it as a saw - tooth wave generator and determine the frequency of oscillation.

g. To design a circuit diagram and study the voltage gain, input impedance, and power gain of an emitter follower.

h. To study the artificial transmission line (TL) at low frequency (<<1kHz) and to determine the line parameters of the given TL.To construct using OPAMP, (i) Differentiator (ii) Integrator (iii) adder-subtractor circuits. To study their performance for different time varying inputs.

i. To determine CMRR, input offset voltage, output offset voltage, input bias current and slew rate of an OP- AMP.

j. To study OP-AMP as voltage comparator. Plot a curve in input and output voltages and show how the output switches from positive to negative value.

k. To design and construct a Wein-Bridge oscillator using OPAMP and to study its output waveform and frequency for various RC values.

l. To study OP-AMP as a function generator, i.e. as (a). square wave generator (b). triangular wave generator.

m. To construct Half-Adder and Full-Adder circuits using logic gates and to perform some simple 2's complement Adder-Subtractor operations (Two decimal digits).

n. To construct X-OR gate using NAND gates and to verify truth table.

1. To convert two inputs NAND gate to two input OR gate.
2. To construct NOR gate by using other gates and hence verify the truth table.

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References:

1. *D Ryder, Electronics Fundamental and application, PHI*
2. *Gaykwad, Operational Amplifier.*
3. *Zee, Physics of semiconductor devices.*
4. *Milman and Grable, Microelectronics. Tata MacGraw Hill.*
5. *R P Jain, Modern digital electronics, Tata mac'Hill.*
6. *J.D.Ryder, Networks line and fields.*

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Semester-II

Core Course-04: Mathematical Methods in Physics-II

Unit-I: LINEAR VECTOR SPACE:
Definition of vector space; dimension, basis, subspace; inner product, orthogonality and completeness. Gram-Schmidt orthogonalization procedure, Linear operators: Representation of operators by matrices.

Unit-II: TENSOR ANALYSIS:
Coordinate transformations, Scalars, Covariant and Contravariant and Mixed tensors. Addition, Subtraction, Outer, Inner product and Contraction. Symmetric and anti-symmetric tensors. Quotient law. Kronecker delta, Levi-civita symbol and metric tensors. Conjugate tensor. Length and angle between vectors. Associated tensors. Raising and lowering of indices. Tensor calculus. Differentiation of a tensor. The Christoffel symbols and their transformation laws. Covariant derivative of tensors.

Unit-III: GREEN'S FUNCTION:
Nonhomogeneous boundary value problem and Green's function, eigen function expansion of Green's function, Fourier transformation method of constructing Green's function, application to physical problems.

Unit-IV: GROUP THEORY:
Introduction, group multiplication table, discrete and continuous groups. Group representations: Faithful and Unfaithful representations, Reducible and Irreducible representation of groups, equivalent representation, representation by unitary matrices, Schur's lemma, orthogonality theorem. Rotation groups, unitary groups and Lorentz homogeneous groups. Rearrangement theorem; Isomorphism and homomorphism; Illustrations with point symmetry groups; Lie groups and Lie algebra with SU(2) as an example.

References:

1. ***George B. Arfken and Hans J. Weber (Academic Press) – Mathematical Methods for Physicists.***
2. ***J. Mathews and R. I. Walker (Benjamin) – Mathematical Methods of Physics.***
3. ***P. Dennery and A. Krzywicki (Harper and Row) – Mathematics for Physicists.***

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Core -5: Statistical Mechanics

Unit-I: SCOPE AND AIM OF STATISTICAL MECHANICS:
Review of the ideas of phase space, phase points, ensemble and ensemble averages. Statistical equilibrium, condition for statistical equilibrium and Transition from thermodynamics to statistical mechanics. Thermodynamic functions, ideal classical gas, relation to thermodynamic quantities, density of distribution (phase points). Liouville's equation and Liouville's theorem.

Unit-II: STATIONARY ENSEMBLES:
Micro canonical, canonical and grand canonical ensembles. Partition function formulation. Fluctuations: Ergodic and quasi-ergodic systems, fluctuations in energy, particle and density; critical opalescence. Equilibrium properties of ideal systems: ideal gas, Harmonic oscillators, rigid rotators, para-magnetism and concept of negative temperature.

Unit-III: CLASSICAL STATISTICS:
Maxwell-Boltzmann distribution; principal of equipartition; inadequacy of classical theory.

Unit-IV: DENSITY MATRIX:
Idea of quantum mechanical ensembles, Statistical and quantum mechanical approaches, properties, pure and mixed states. Equilibrium properties of a system of ideal gases in micro canonical and grand canonical ensembles. Density matrix for stationary ensembles. Application to a free particle in a box, an electron in a magnetic field. Density matrix for a beam of spin ½ particles. Construction of the density matrix for different states (pure and mixture) and calculation of the polarization vector.

Unit-V: DISTRIBUTION FUNCTIONS:
Bose-Einstein and Fermi-Dirac statistics. General equations of state for ideal quantum systems.

Unit-VI: IDEAL QUANTUM SYSTEMS:
Properties of ideal Bose gas: Bose-Einstein condensation: Transition in liquid He4, Superfluidity in He4. Photon gas: Planck's radiation law. Phonon gas: Debye's theory of specific heat of solids.
Properties of ideal Fermi gas: Degenerate Fermi gas. Review of the thermal and electrical properties of an ideal electron gas. Landau levels, Landau diamagnetism.
Some applications: Specific heats of diatomic gases and crystalline solids; Einstein and Debye models; chemical equilibrium; thermal ionization; imperfect gases. Cluster and cluster integrals; The second viral coefficient; van der Wall's equation; cluster expansion of the equation of state of real classical gas.
Irreversible processes: Onsager's reciprocal relations; applications.

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Unit-VII: STRONGLY INTERACTING SYSTEMS:

Ising model. Idea of exchange interaction and Heisenberg Hamiltonian. Ising Hamiltonian as a truncated Heisenberg Hamiltonian. Exact solution of one-dimensional Ising system (Matrix methods). Bragg-William's approximation (Mean field theory) and the Bethe-Peierls approximation.

References:

1. ***R. K. Pathria, Statistical Mechanics***
2. ***K. Huang, Introduction to Statistical Mechanics***
3. ***Silvio R. A. Salinas, Introduction to Statistical Mechanics.***
4. ***F. Reif, Fundamentals of Statistical and Thermal Physics.***
5. ***Kadanoff, Statistical Mechanics. World Scientific.***
6. ***R. Kubo, Statistical Mechanics. (Collection of problems)***
7. ***Sanchez Bowley, Introductory Statistical Mechanics, Oxford University Press***

Core -6: Atomic and Molecular Physics

Unit-I: ONE-ELECTRON ATOMIC SYSTEM:

Quantum states, atomic orbitals; H-atom spectrum, fine structure of H-atom, Lamb-Rutherford experiment, Lamb shift, hyperfine structure.

Unit-II: TWO-ELECTRON ATOMIC SYSTEM:

Spectral terms, exchange degeneracy, singlet and triplet structure; LS, JJ and mixed coupling schemes.

Unit-III: MANY-ELECTRON ATOMIC SYSTEM:

Independent particle model, central field approximation, Russel- Saunders coupling, alkali spectra, fine and hyperfine structure in alkali spectra.

Unit-IV: INTERACTION WITH EXTERNAL FIELDS:

Time dependent perturbation treatment, electric dipole approximation, stimulated and spontaneous emission, absorption coefficients, selection rules, line broadening, Stark effect.

Unit-V: LASER:

Emission broadening, Absorption and Gain. Homogeneous broadening, Doppler broadening, Threshold conditions, Einstein's A, B coefficients. Population inversion. Creation of population inversion in 3 level and 4 level lasers. Pumping requirements. Laser cavity modes and coherence length, Fabry Perot resonator, Laser cavity modes and its properties, Q switching, Mode-Locking, Nd: YAG laser.

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Unit-VI: MOLECULAR ORBITALS:

Linear combination of atomic orbital, Hydrogen-molecular ion, Hydrogen-molecule, HeitIer London theory.

Unit-VII: MOLECULAR SPECTRA:

Rotation of a diatomic molecule, rotational transition, selection rules, rotational spectra of diatomic molecules as rigid rotor and as non-rigid rotors Stark effect in molecular rotation spectra. Diatomic molecules as linear symmetric top and asymmetric top. Vibration of diatomic molecules, harmonic oscillator, an-harmonicity, selection rules and spectrum, symmetry property of molecular vibration, intensity of spectral lines. Rotation- vibration spectra of diatomic molecules, P, Q and R branching, Raman spectroscopy – pure rotational spectra and vibrational spectra. Electronic spectra of diatomic molecules, Frank- Condon principle. Born-Oppenheimer approximation, vibrational and rotational structure.

References:

1. ***Introduction of atomic spectroscopy: White***
2. ***Introduction to molecular spectroscopy: Rajkumar***
3. ***Laser Spectroscopy: Allan Corney***
4. ***Laser in Chemistry- D L Andrew***

GE: Solid State Physics

Unit-I: ELEMENTARY CRYSTALLOGRAPHY:

Crystal lattice and symmetry; unit cell; Bravais lattices; Miller indices; Bragg's law; Laue diffraction; reciprocal lattice; simple crystal structures x-ray diffraction; Bragg's law; atomic scattering factor; crystal structure factor, neutron diffraction; electron diffraction.

Unit-II: CRYSTAL BINDING:

Different types of binding; simple theory of ionic crystals; van der Wall's interaction.

Unit-III: DIELECTRIC PROPERTIES OF INSULATORS:

Static dielectric constant: complex dielectric constant; dielectric loss; classical theory of electric polarization; ferro-electricity.

Unit-IV: LATTICE VIBRATIONS:

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Vibrations monatomic and diatomic chains; acoustical and optical lattice vibrations in crystals; dispersion relation; an-harmonic vibrations and thermal expansion.

Unit-V: FREE ELECTRON FERMI GAS:

Classical free electron theory; its failures; Fermi-Dirac probability distribution function; periodic boundary conditions in a solid; density of states; Fermi energy- its dependence upon temperature; electronic specific heat of solid; Para-magnetism of free electrons.

Unit-VI: BAND THEORY:

Bloch theorem; motion of electrons in a periodic lattice; Brillouin zones for simple lattices; crystal momentum; effective mass; nearly free electron approximation; tight binding approximation; application to simple cubic lattices; ideas of Fermi surfaces; band structure of simple elements.

Unit-VII: MAGNETIC PROPERTIES OF SOLIDS:

Diamagnetism; paramagnetic susceptibility; behavior of the rare earths and the iron group of metals; Hund's rules; ferromagnetism; classical theory; Weiss' theory; Heisenberg exchange energy; domain structure; elementary ideas of ferri- and anti-ferro magnetism; Neel temperature.

Unit-VIII: SEMICONDUCTORS AND THEIR PROPERTIES:

Intrinsic and extrinsic semiconductors; mechanism of conduction in semiconductors; motion of hole-electron pair-carrier transport equation, Hall effect.

Unit-IX: SUPERCONDUCTIVITY:

Properties of super conductors, type I and II super conductors; super conducting magnets; Meissner effect; London's equations; electron tunneling; Josephson effect.

References:

1. ***F.C.Phillips: An introduction to crystallography (wiley)(3rd edition)***
2. ***Charles A Wert and Robb M Thonson: Physics of Solids***
3. ***J. P. Srivastava: Elements of solid state physics (Prentice Hall India; 2nd edition).***
4. ***Christmaan-solid state physics (academic press)***
5. ***A R Verma & O N Srivastava, Crystalolgraphic application to solid state physics***

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Semester-III

CP-1: Quantum Mechanics –II and Relativistic Kinematics

Unit-I: MANY PARTICLE SYSTEMS:

Identical particles, exchange degeneracy, symmetrization postulate, symmetric wave function and bosons, asymmetric wave function and fermions, Pauli's exclusion principle, BE and FD statistics, second quantization formalism, one and two particle operators in second quantization formalism.

Unit-II: SCATTERING THEORY:

Partial wave analysis, phase shift, applications, Coulomb scattering, Green's function in scattering theory, Born approximation.

Unit-III: RELATIVISTIC QUANTUM MECHANICS:

Lorentz group, Klein-Gordon equation, Dirac equation and its plane wave solution, spin and magnetic moment of an electron, negative energy states and its interpretations, covariance of Dirac equation, construction of covariant quantities, large and small components, Pauli's theory as non-relativistic approximation, higher order corrections, central potential, H -atom.

Unit-IV: FIELD QUANTIZATION:

Quantization of a real scalar field and complex scalar field. Quantization of the electromagnetic field, photons, interaction of an atom with radiation field, emission and absorption of radiation. Quantization of Dirac field.

Unit-V: SPECIAL THEORY OF RELATIVITY:

Lorentz Transformations, Tensor Analysis: Raising and lowering of indices, Contraction, Symmetric and antisymmetric tensors; Four-Vectors: vectors and tensors in Minkowski space-time, Metric tensor, 4-velocity and 4-momentum; energy-momentum, Matrix Representation of Lorentz Transformations; Covariant equations of motion; Lagrangian of a free relativistic particle.

References:

1. ***Quantum Mechanics, L.I. Schiff***
2. ***Modern Quantum Mechanics, J.J. Sakurai***
3. ***A Text Book of Quantum Mechanics, P.M. Mathews and K. Venkatesan***
4. ***Relativistic Quantum Mechanics, J.D. Bjorken and S.D. Drell***
5. ***Relativistic Quantum Mechanics, W. Greiner***

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6. *A First Book of Quantum Field Theory, A. Lahiri and P.B. Pal*
7. *Quantum Mechanics, B. H. Bransden and C. J. Joachain*
8. *Quantum Mechanics, A. K. Ghatak and S. Lokenathan*
9. *Introduction to Field Theory, S. Weinbrg*

CP-2: Nuclear and Particle Physics

Unit-I: NUCLEAR MODELS AND BASIC PROPERTIES OF NUCLEI:

Shell model- experimental evidences - spin-orbit coupling; spin, parity, quadrupole moment, and magnetic moment of nuclear ground states - Schmidt lines; inadequacy / limitations of the shell model.

Unit-II: INTERACTION OF RADIATION WITH MATTER:

Interaction of heavy particles with matter - specific ionization - Bethe's theory - straggling. Interaction of electrons with matter - range energy relations - Bremsstrahlung: Interaction of gamma radiation with matter - photoelectric effect, Compton scattering and pair production.

Unit-III: NUCLEAR INTERACTIONS AND NUCLEAR REACTIONS:

Ground state of deuteron; nucleon-nucleon scattering (low energy) - magnetic moment and quadrupole moment - spin dependence and charge independence of nuclear force. Compound nuclear reaction - reciprocity theorem - Breit-Wigner one-level formula resonance scattering - Ghosal' s experiment.

Unit-IV: ACCELERATORS AND DETECTORS:

Cyclotron, synchrocyclotron, synchrotron, betatron - phase stability and phase oscillation. Geiger-Muller counter, bubble chamber, scintillation detector, Cerenkov detector, and semiconductor detector.

Unit-V: NUCLEAR DECAY:

Alpha decay - Gamow's theory - alpha spectrum and systematics. Beta decay -Ferni's theory on beta decay - beta spectrum - selection rules - allowed and forbidden transitions - parity violation - neutrinos. Gamma decay - multipole transition - angular momentum and parity selection rules - internal conversion - nuclear isomerism.

Unit-VI: NEUTRON PHYSICS AND BASIC THEORY OF NUCLEAR REACTORS:

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Passage of neutrons through matter; slowing down, absorption, diffusion and leakage - equation of continuity - Fermi age. Nuclear reactor - condition of criticality - critical size of infinite homogeneous reactors of different shapes.

Unit-VII: COSMIC RAYS:

Origin of primary cosmic rays - composition and energy spectrum, pions and muons - properties and production - Stroemer's theory - cosmic rays in atmosphere.

Unit-VIII: ELEMENRATY PARTICLES:

Different types of interaction of elementary particles classification of elementary particles, isospin and its conservation - SU(2) and SU(3) multiplets - quark model - Gellman-Okubo mass formula; Quantum chromodynamics, quark confinement, asymptotic freedom.

References:

2. Nuclear Physics- S. N. Ghoshal (S. Chand Publications)

3. Nuclear Physics- D. C. Tayal (Himalaya Publications)

4. Introductory Nuclear Physics- K. S .Krane (Wiley India)

5. Nuclear Physics: Theory and Experimental- H. S. Hans (New Age International)

6. Nuclear Physics: Theory and Experiment- R. R. Roy and B. P. Nigam (John Wiley and Sons)

CP-3: Electrodynamics and Plasma Physics:

Unit-I: RECAPITULATION OF ELECTRODYNAMICS:

Maxwell's equations, scalar and vector potentials, Lorentz and Coulomb gauge, electromagnetic field tensor, dual field tensor, wave equation for vector and scalar potentials and its solution.

Unit-II: FIELD OF MOVING CHARGES AND RADIATION:

Retarded potential and Lienard-Wiechert potential. Radiation fields, radiated energy and application to linear antenna, Hertz potential and dipole radiation fields, multipole radiation fields. Electric and magnetic fields due to a uniformly moving charge and an accelerated charge, linear and circular acceleration and angular distribution of radiated power, Bremsstrahlung, synchrotron radiation and Cerenkov radiation.

Unit-III: MOTION' OF CHARGED PARTICLES IN ELECTROMAGNETIC FIELD:
Uniform E and B fields, non-uniform fields, diffusion across magnetic fields, time-varying E and B fields. Adiabatic invariants: first, second and third adiabatic invariants.

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Unit-IV: SCATTERING OF RADIATION:
Differential scattering cross-section, Thomson and Rayleigh scattering, Radiation reaction, Abraham-Lorentz model, Line width of radiation spectrum due to radiation reaction.

Unit-V: ELEMENTARY CONCEPTS OF PLASMA:

Derivation of moment equations from Boltzmann equation, plasma oscillations, Debye shielding, plasma parameters, magneto plasma, plasma confinement.

Unit-VI: HYDRO-DYNAMICAL DESCRIPTION OF PLASMA:

Fundamental equations. Hydro-magnetic waves; magneto-sonic and Alfven waves.

Unit-VII: WAVE PHENOMENA IN MAGNETO-PLASMA:

Polarization, phase velocity, group velocity, cutoffs, resonance for electromagnetic wave propagating parallel and perpendicular to the magnetic field, propagation at a finite angle and CMA diagram. Appleton- Hartree formula and propagation through ionosphere and magnetosphere: helicon, Whistler modes and Faraday rotation.

References:

1. ***Marion- Classical Electrodynamics***
2. ***Jackson- Classical Electrodynamics***
3. ***Panofsky & Phillips- Classical Electrodynamics***
4. ***Chen- Plasma Physics***
5. ***Griffith-Electrodynamics***

RP -1: Research Methodology and Project-I (Literature Review on a specific topic as prescribed by the supervisor)

Numerical Analysis and Programming:

Unit-I: NUMERICAL ROOT FINDING:
Solution of polynomial equations: Bisection method, False position method, Newton-Rapson method and Secant method, Multidimensional Newton's method.

Unit-II: INTERPOLATION AND LEAST SQUARE FITTING:
Linear Interpolation, Newton and Lagrange Interpolation, Linear and non-linear curve fitting.

Unit-III: MATRIX AND SOLUTION OF SYSTEM OF SIMULTANEOUS EQUATIONS:

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Matrix diagonalization and matrix inversions, Eigen value problems, Gauss elimination, Gauss Jordan elimination method, Pivoting.

Unit-IV: NUMERICAL DIFFERENTIATION AND INTEGRATION:

Numerical formulae for ordinary derivative and partial derivative, Trapezoidal formula and Simpson's formula for numerical integration, Numerical multiple integral.

Unit-V: NUMERICAL TECHNIQUES FOR SOLVING DIFFERENTIAL EQUATION:
Ordinary differential equation, Initial value problems and boundary value problems, Taylor series method, Euler's method, Runge-Kutta fourth order method, Shooting method, Finite difference method, Partial differential equation, Application of numerical techniques to solve Poisson's equation, Wave equation, Heat equation, Schrödinger equation.

Unit-VI: RANDOM NUMBERS AND MONTE-CARLO SIMULATION:
Introduction to random numbers, Monte-Carlo simulations, Evaluation of "π" by Monte-Carlo method, Monte-Carlo technique of numerical integration, Metropolis algorithm.

Unit-VII: MACHINE LEARNING:
Introduction to machine learning and its applications.

References:

1. ***Introductory Methods of Numerical Analysis, S. S. Sastry, PHI Learning; 5th edition, 2012***
2. ***Computer Oriented Numerical Methods:V. Rajaraman, PHI Learning; 4th edition, 2019***
3. ***Numerical Recipes in C++ : The Art of Scientific Computing; William H. Press, Saul A. Teukolsky, T. Vetterling and Brian P. Flannery, Cambridge University Press; 2nd edition, 2002***
4. ***Scientific Computing in Python by Abhijit Kar Gupta***
5. ***Numerical Analysis: C. F. Gerald, P. O. Wheatley***
6. ***Numerical Methods for Scientific and Engineering Computation : Jain, Iyengar and Jain***
7. ***Numerical Analysis: Richard L Burden and J Douglas Faires***
8. ***Computational Physics : J M Thijssen .***
9. ***Numerical Recipes in C : The Art of Scientific Computing : Press, Teukolsky, Velleling and Flannery***
10. ***Numerical Mathematical Analysis : Scarborough, James B***

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Semester-IV

RP -2: Astrophysics and Cosmology-I/Nuclear Physics and Particle physics I/Solid State Physics I (one course from the cluster)

Astrophysics and Cosmology-I

Unit-I: MOTIVATION:

Precession of perihelion of mercury, bending of light, Radar echo delay from Newtonian viewpoint; qualitative discussions.

Unit-II: GEOMETRICAL FRAMEWORK OF GENERAL RELATIVITY:

Gravitational and inertial mass, principle of equivalence (PE) and general covariance; Mach's principle. Riemannian geometry; vectors and tensors; parallel transport, integrability of parallel transport; covariant differentiation, geodesics; Riemann Christoffel curvature tensor, Bianchi identity; Ricci tensor; curvature scalar; Kretschmann scalar, condition of flatness; Einstein tensor, Weyl tensor, Symmetries and Killing vectors. Energy momentum tensor; conservation laws; gravitational red-shift. Derivation of Einstein's field equation;

Unit-III: APPLICATION OF GENERAL RELATIVITY:

Perihelion of Mercury, Bending of light, Gravitational lensing, radar echo delay.

Unit-IV: SOLUTIONS OF EINSTEIN EQUATION IN VACUUM:

Schwarzschild exterior solution; Schwarzschild singularity; integrals of motion; conditions for circular orbits; Innermost Stable Circular Orbit (ISCO), event horizon and black hole; Eddington-Finkelstein coordinates; Kruskal transformation; Kerr metric (without deduction).

Unit-V: GRAVITATIONAL WAVE:

Linearized Einstein field equations, Derivation of wave equations under gravitational gauge and gravitational wave. Detection of gravitational waves qualitatively.

References:

1. ***Black holes, white dwarfs and neutron stars, S.L. Shapiro and S. A. Teukolsky, J Wiley, 1983.***
2. ***Gravitation and Cosmology: Principles and applications of the General Theory of Relativity- S. Weinberg, John Wiley, 1972.***
3. ***A First Course in general relativity – B. F. Schutz (CUP)***
4. ***General Relativity : R M Wald***
5. ***Lecture notes on general relativity: S. Carroll***

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6. *Introduction to General Relativity : G. t'Hooft*

Nuclear Physics and Particle Physics I:

Unit-I: TWO-NUCLEON SYSTEM:

Deuteron problem - ground state of deuteron with non-central force, quadrupole moment and magnetic moment. Scattering length, effective range theory for n-p and p-p scattering at low energy - saturation of density and binding energy, exchange force.

Unit-II: NUCLEAR MODELS:

Evidence of collective model, phenomenological collective model, rotational and vibrational states, coupling of single particle with collective motion, single particle in deformed potential- Nilsson model.

Unit-III: NUCLEAR INTERACTIONS AT HIGH ENERGY:

Nucleon-nucleon interaction at high energy and hadron structure, nucleon-nucleon potentials, meson theory, Yukawa interaction, polarization in nucleon-nucleon scattering, scattering matrix. Probing charge distribution with electrons, form factors, deep inelastic e-p scattering.

Unit-IV: NUCLEAR REACTIONS:

Theory of elastic and inelastic scattering, coupled channels - distorted wave Born approximation - optical model, limitations of optical model. Statistical theory of compound nucleus, resonances; theory of direct reaction. Ghosal's experiment.

Unit-V: ACCELERATORS AND DETECTORS:

Principle of phase stability and phase oscillation in case of synchrocyclotron and synchrotron. Betatron oscillations. Linear accelerators, Pelletrons and microtrons. Focusing of particle beam, sector focused cyclotron, alternating gradient focusing.

Unit-VI: DETECTORS:

Proportional counters, multi-wire proportional counters, Drift chamber, Streamer chamber, Calorimeters.

References:

1. *An Introduction to Particle Accelerators (Oxford University Press 2001) Edmund Wilson*
2. *Principles of Charged Particle Acceleration (Wiley 1986) Stanley Humphries, Jr.*

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3. *Principles of Cyclic Particle Accelerators (Van Nostrand, NJ 1961) John Jacob Livingood*
4. *. M. A. Preston and R. K. Bhaduri, (1982), Structure of the Nucleus, Addison wesley,*
5. *M. K. Pal, (1982), Theory of Nuclear Structure, East-west Press.*
7. *W. E. Burcham and M. Jobes, (1998), Nuclear and Particle Physics, AddisonWesley,*
8. *B. Povh, K. Rith, C. Scholz, F. Zetsche, (1995) Particles and Nuclei, Springer*
9. *Rolfs and Rodney, Cauldrons in Cosmos: Nuclear Astrophysics, Chicago University Press*

Solid State Physics I

Unit-I: LATTICE DYNAMICS:

Born-Oppenheimer approximation; phonons; photon-phonon, electron- phonon and neutron-phonon interactions; N-process and U-process; phonon spectrum; singularities in phonon spectrum; Van Hove's theorem (statement only); Debye-Waller factor; an-harmonic effects; thermal expansion and thermal conductivity for determining phonon dispersion curves.

Unit-II: FERROMAGNETISM:

Exchange interaction and Heisenberg's theory of ferromagnetism; Block's theory of free electron ferromagnetism; collective electron theory; magnons; magnon dispersion relation (for both ferro and anti-ferromagnetic substances); Block's T 3/2 law; neutron scattering by magnons; Ising model; Landau's theory of diamagnetism.

Unit-III: MAGNETIC RESONANCE:

Basic theory; spin-spin and spin -lattice relaxation processes; Bloch equations; steady state solutions; Bloch susceptibilities; line width; motional narrowing; nuclear magnetic resonance (NMR); Knight shift in metals; electron spin resonance (ESR); crystal field theory; ENDOR; Overhauser effect; methods for measuring relaxation times; SWR, RME, AFFMR, Mossbauer effect; Mossbauer's experiment, Mossbauer coefficient - classical and quantum theory, red shift, isomer shift, quadrupole coupling, magnetic hyperfine structure.

References:

1. *P.M. Chaikin and T.C. Lubensky, (1998) Principle of Condensed Matter Physics, Cam.Univ.Press*
2. *J.P. Hansen and I.R. McDonell, (2006), Theory of Simple Liquids, Elsevier Inc.*
3. *P.G. de Gennes, (1979), Scaling Concept in Polymer Physics, Cornell Univ. Press*

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4. *J.D. Cloizeanx and G. Jannink, (1990), Polymer in Solutions: Their modelling and structure, Oxford Univ. Press*

5. *S. Singh, (2002), Liquid Crystals: Fundamentals, World Scientific*

6. *G.D. Mahan, Many, (1990), Particle Physics, Springer*

7. *Nigel Goldennfeld, (1992), Lectures on Phase Transitions and the renormalization group, Addison-Wisley*

8. *S.Puri and V.K. Wadhawan, (2010), Kinetics of Phase Transitions, World Scientific*

RP -3: Astrophysics and Cosmology-II/Nuclear Physics and Particle physics II/Solid State Physics II (one course from the cluster)

Astrophysics and Cosmology-II

Unit-I: ASTRONOMICAL UNITS AND PARAMETERS:
Luminosity, stellar magnitudes, distance modulus relation, parallax methods.

Unit-II: CELESTIAL COORDINATES:
Naming convention of astronomical objects, catalogues Astronomical observation: different spectrum bands, H-R diagram: classification of stellar objects from HR diagram.

Unit-III: STAR FORMATION:
Pre-main sequence star, main sequence star, Virial theorem. Thermal paradox, Kelvin Helmholtz time scale, Radiative transfer equation.

Unit-IV: BASIC EQUATION OF STELLAR STRUCTURE:
Newtonian Stars, Hydrostatic equilibrium, Homologous stellar models, mass-luminosity relation, Relation to HR diagram. Polytropic equation of state, Lane- Emden equation and its analytic solutions.

Unit-V: SUN:
General features. Solar activities, Zurich number & 11 years structure cycle.

Unit-VI: THERMONUCLEAR REACTIONS IN STARS:
pp chain, CNO cycle; solar neutrino problem, subsequent thermonuclear reactions, Helium burning, nucleosynthesis beyond iron.

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Unit-VII: STELLAR EVOLUTION:
white dwarf, Electron degeneracy pressure, Chandrasekhar mass limit,

Unit-VIII: STATIC SPHERICALLY SYMMETRIC SPACE-TIME:
Physical interpretation of metric potentials. Gravitational red-shift.

Unit-IX: PERFECT FLUID:
Equation of state, equation of motion, TOV equation, stars of uniform density, limit of mass to radius ratio. Newtonian Limit.

Unit-X: NEUTRON STARS:
Schematic Structure and general features. TOV equation applied to neutron stars, Neutron degeneracy pressure, Maximum mass of neutron stars. Pulsars.

Unit-XI: BLACK HOLES:
Binary stars accretion, Roche Lobe and Lagrange points; accretion process, qualitative formation of black holes, Schwarzschild black hole, Event Horizon and its nature, infinite red-shift, Removal of coordinate singularity, Eddington- Finkelstein and Kruskal-Szekres coordinates, Penrose diagram. No hair theorem (statement only) Hawking Area Theorem (statement only), surface gravity, four laws of BH thermodynamics, Penrose process, Hawking Radiation (qualitative discussion), BH evaporation. Active galactic nuclei, Super massive black holes, Quasi-stellar Objects (Quasars), Blazers.

References:

1. ***Black holes, white dwarfs and neutron stars, S. L. Shapiro and S. A. Teukolsky,***
2. ***John Wiley, 1983.***
3. ***An introduction to the study of stellar structure, S. Chandrasekhar, Dover.***
4. ***Relativistic astrophysics, Ya B. Zel'dovich and I.D. Novikov, Vol.-I, University of***
5. ***Chicago press.***
6. ***Theoretical astrophysics, Vol.-I, II and III, T. Padmanabhan, CUP.***
7. ***Gravitation and Cosmology: Principles and applications of the General***
8. ***Theory of Relativity- S. Weinberg, John Wiley, 1972.***
9. ***Gravity: Hartle (Pearson Education)***
10. ***A First Course in general relativity – B. F. Schutz (CUP)***
11. ***General Relativity : R M Wald***
12. ***Lecture notes on general relativity: S. Carroll***
13. ***Introduction to General Relativity : G. t'Hooft***

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14. *Introduction to Modern Astrophysics: Bradly W. Carroll and*
15. *Dale A. Ostlie, (Pearson)*
16. *Astrophysics: Arnab Raychaudhuri*

Nuclear and Particle Physics II

Unit-I: INTRODUCTION TO QUANTUM FIELD THEORY:

Introduction to Klein-Gordon and Dirac equations, solutions and antiparticles, γ-matrices, bilinear covariants, spin and helicity, two component theory of neutrinos. Canonical quantization of scalar, electromagnetic and Dirac fields; interacting fields: λ^4 theory. Introduction to quantum electrodynamics (QED), Feynman diagrams and Feynman rules.

Unit-II: HEAVY-ION COLLISIONS:

Importance of ultra-relativistic heavy-ion collisions, collision scenarios and formation of dense hadronic matter, possibility of the formation of a novel state of matter called quark gluon plasma (QGP), conditions for the formation of QGP, QGP at high-temperature; QGP at high baryon density. Hydrodynamics of QGP; Bjorken's estimation of energy density in high-energy nucleus-nucleus interaction. Signatures of QGP – qualitative discussion, Conditions for the application of thermal models and Resume of thermodynamics, state of thermo-chemical equilibrium in nucleus-nucleus reactions, Grand canonical treatment, phase transition theory for hadron to quark transition, application in ideal gas of quarks and gluons within M.I.T Bag model, criteria for a first order quark-hadron phase transition, phase transition at zero temperature, phase transition at finite temperature, phase boundary of quark-hadron phase transition. Evolution of quark-gluon plasma and light quark-antiquark pair and heavy (strange) quark-antiquark production, influence of Pauli blocking of final states, results for static quark gluon plasma, strange particle production in baryon rich plasma. strangeness abundance in hadronic gas in chemical equilibrium, influence of volume (or hydrodynamic) expansion, hadronization scenarios. Signals of quark gluon plasma: strangeness abundances, di-lepton and hard photon production, J/Ψ formation.

Unit-III: RELATIVISTIC KINEMATICS:

Laboratory system and C.M. system, Lorentz transformation; Mandelstam variables, invariant cross-section, phase space density.

References:

1. *D.J. Griffiths, (1987), Introduction to Elementary Particles, John Wiley & Sons*
2. *F. Halzen and A D Martin, (1984), Quarks and Leptons, John Wiley & Sons*

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3. *Lahiri and P B Pal, (2001), A first book of Quantum Field Theory, Norosa Das, (2008), Lectures on Quantum Field Theory, World Scientific*

4. *M E Peskin and D V Schroeder (2005), An Introduction to Quantum Field Theory, West view Press*

5. *I J R Aitchison and A J G Hey, (1982), Gauge Theories in Particle Physics (Vol. I), Adam Hidger*

6. *D H Perkins,(1987), Introduction to High Energy Physics, Addition Wesley*

7. *"Finite-Temperature Field Theory Principles and Applications" by Joseph I. Kapusta and Charles Gale, Cambridge Monographs on Mathematical Physics, Cambridge University Press.*

Solid State Physics II

Unit-I: SUPERCONDUCTIVITY:

Heat capacity and infra-red properties of superconductors; London equation; penetration depth; coherence length; Cooper theory; Cooper pairs; BCS theory; quasi particles; flux quantization; Grover tunneling; Josephson tunneling; AC and DC effects; SQUID.

Unit-II: CRITICAL PHENOMENA:

Order parameter; Landau theory; first & second order phase transitions; critical indices; scale invariance hypothesis; effective Hamiltonian; fluctuations of order parameter, examples of systems sharing critical behavior.

Unit-III: STRUCTURE DETERMINATION OF SOLIDS:

Crystal symmetry, Bravais lattice; transformation of crystal lattices; point groups; space groups; simple application of group theory to symmetry of crystals; space group determination; rotation and Weissenberg photographs; Fourier transform and its application; theory of structure analysis; Patterson synthesis and its application in structure determination; direct methods of crystal structure determination; diffraction of X- rays in presence of thermal vibrations; electron diffraction and neutron diffraction for structure determination. Advantage of neutron diffraction over X-ray diffraction, general idea of defects in crystals, color centers; quasi crystals, Nanomaterials; liquid crystals; Elementary concepts of surface crystallography, scanning, tunneling & atomic force microscopy.

Unit-IV: BAND THEORY OF SOLIDS:

Calculation of energy bands in solids; tight binding and LCAO methods; OPW method; cellular and augmented plane wave method; symmetry of energy bands; calculated energy bands; experimental

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study of electronic energy levels in solids; cyclotron resonance; anomalous skin effects; de Haas-van Alphen effect.

References:

1. *S.M. Sze, (2003), Semiconductor Devices Physics and Technology, John Wiley & Sons, Inc 2. K.L. Chopra, (2008), Thin Film Phenomenon, Krieger Pub. Co.*
2. *F.M. Grey, (1991), Solid Polymer Electrolytes Fundamentals and Technological Application VCH Publishers, Inc*
3. *Pratt, Application of Conducting Polymers*
4. *J. Przyluski and S. Roth, (1993), Conducting Polymers-Transport Phenomena, Trans. Tech. Pub.*

RP -4: Astrophysics and Cosmology-III/Nuclear Physics and Particle physics III/Solid State Physics III (one course from the cluster)

Astrophysics and Cosmology-III

Unit-I: INTRODUCTION TO COSMOLOGY:
Cosmological Principle, observational basis for cosmological theories, Olbert Paradox, Hubble's law, Cosmological red shift, big bang theory.

Unit-II: HOMOGENEOUS ISOTROPIC WORLD MODELS:
Robertson Walker metric, Derivation of Friedman models, Dynamics of FRW model, Discussion on closed, open, and flat universe.

Unit-III: PHYSICS OF THE BIG BANG:
Thermal history of the universe, cosmological nucleosynthesis, the cosmic microwave background radiation (CMBR), the decoupling era, large- and small- scale anisotropy in the CMBR. Problems of the Standard Model and its remedies. Concept of inflation in the early universe.

Unit-IV: GALAXY:
Milky Way as a galaxy, Classification and morphology of galaxies, dynamics of galaxies, rotation curves and dark matter, galaxy properties, scaling relations.

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Unit-V: LARGE SCALE STRUCTURE OF THE UNIVERSE:
Red-shift surveys of galaxies, measures of the galaxy distribution, correlation functions and power spectra, topological measures of galaxy distribution.

Unit-VI: REIONIZATION OF THE UNIVERSE:
The first stars, Dark Age of the universe, the reionization process.

References:

1. ***Introduction to Cosmology: J. V. Narlikar, CUP***
2. ***Modern Cosmology: S. Dodelson, Academic Press***
3. ***Gravitation: C. W. Misner, K. S. Thorne and J. A. Wheeler, W. H. Freeman and Co.***
4. ***Cosmology and Astrophysics through problems: T. Padmanabhan, CUP***

Lab:

Introduction to Mathematica, LaTeX, Data analysis.

Part-I: Computer application

Mathematica:
Concepts of CAS, Basics operations in Mathematica, elementary calculations, Algebra, Calculus, Numerical Analysis, Graphics and plots, Functions,
Writing elementary programs, Do-While loop.

Latex:
Fundamentals, Creating a document, article, book, Writing equations. Formatting tables. \usepackage commands, Inserting figures, Writing long documents, \input, \include commands, defining macros, \def, \newcommand, \renewcommand, Composing presentations.

Nuclear Physics and Particle Physics III

Unit-I : HIGH ENERGY PHYSICS ACCELERATORS:

Classification of accelerators, principle and design of ion-sources, Linear accelerators, Large Hadron Collider (LHC), Relativistic Heavy Ion Collider (RHIC), Tevatron, storage rings.

Unit-II: DETECTORS FOR IONIZATION AND TRACK MEASUREMENTS:

Detection of charged particles, ionization chambers, proportional counters, muti-wire proportional counters (MWPC), drift chambers, Particle measurements in liquids.

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Unit-III: PARTICLE IDENTIFICATION:

Cherenkov radiation in anisotropic and optically active media, Cherenkov radiation and bremsstrahlung, Cherenkov detectors, Classification of Cherenkov detectors (focusing and non-focusing type), transition radiation detectors; Choice of photomultiplier, Comparison of particle identification methods.

Unit-IV: DATA ANALYSIS:

Input from detectors for data analysis, Pattern recognition and track reconstruction, Event reconstruction, Event generators, Detector simulation

References:

1. ***Quark Gluon and Hadron Physics, Eds. P.K. Sahu, S.C. Phatak, Y.P. Viyogi, Narosa Publishing House.***
2. ***The Physics of the Quark-Gluon Plasma, Lecture Notes in Physics by Berndt Muller, Springer-Verlag***
3. ***"Quark-Gluon Plasma", Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology by K. Yagi, T. Hatsuda and Y. Miake, Cambridge University Press.***
4. ***"Quarks and Gluons at High Temperatures and Densities" by J. Cleymans, R.V. Gavai and E. Suhonen, Physics Reports, Vol. 130, No. 4, pp 217 – 292.***
5. ***"Strangeness in Relativistic Heavy Ion Collisions", by P. Koch, B. Muller and J. Rafelski, Physics Reports, Vol. 142, No. 4, pp 167 – 262.***

Lab:

1. To study the gamma ray spectra using a scintillator detector and a single channel analyzer.
2. To calibrate the gamma ray spectrometer, and to find out its resolution and efficiency for gamma detection.
3. Measurement of Compton scattering cross-section and photoelectric effect cross-section.
4. To study gamma absorption in Pb/Hg using gamma ray spectrometer.
5. To study the beta absorption in AI, using G.M. counter - Feather's method.
6. To study the characteristics curve of G.M. counter, and (a) to study the statistical fluctuation in cosmic ray background radiation, (b) to study the decay of activity of an artificially activated source, (c) to find out the gamma counting efficiency of G.M. tubes, (d) to study the gamma absorption in lead, (e) to study the beta absorption in Aluminum and hence to determine maximum beta energy.
7. To study Rutherford's scattering of alpha particles.
8. To study the beta spectrum from different beta sources.

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9. To study the Compton Effect using scintillator.
10. To study (i) the hadronic interactions, (ii) heavy-ion interactions, (iii) pi-mu decay, and (iv) to measure charge of nuclear fragments in nuclear emulsion.

Solid State Physics III

Unit-I: SEMICONDUCTORS:

Band structure of common semiconductors; effective mass theory; intrinsic and extrinsic semiconductor - statistics of electron-hole carriers and Fermi energy; dynamics of electrons and holes; generation and recombination processes; surface recombination; Shockley-Reed mechanism of recombination; life time of carriers; Hall effect and Hall coefficient for two carrier types, origin of positive Hall coefficient for metals, modification of Hall coefficient for velocity distribution of carriers.

Unit-II: DIELECTRIC PROPERTIES:

Dielectric polarization; Debye's theory of dielectric relaxation, Cole- Cole plot, Onsager-Kirkwood theory, Ferroelectricity; ferroelectric crystals Barium Titannate etc. ; polarization catastrophe; LST relation in ferroelectrics.

Unit-III: OPTICAL PROPERTIES:

Drude-Lorenz theory of metals and insulators; complex dielectric constant and its relation with optical properties of a solid; dispersion and absorption; reflection and absorption coefficients; Kramers-Kronig relations; quantum theory of optical transitions in a solid; direct and indirect, allowed and forbidden transitions; excitons; Frenkel and Mott- Wannier excitons.

References:

1. ***Introduction to Solid State Physics, C. Kittel***
2. ***Solid State Physics, A. J. Dekker***
3. ***Solid State Physics, Ashcroft and Mermin***
4. ***Solid State Physics, S. O. Pillai***
5. ***Elements of Solid State Physics, J. P. Srivastava***
6. ***An Introduction to Solid State Physics and Application, R. J. Elliot and A. F. Gibson***
7. ***Solid State Physics, D. W. Snoke***

Lab: (List of experiments should be regarded as suggestive of the standard and may not be strictly adhered to. New experiments of similar standard may be added and old experiments may be deleted whenever felt it necessary).

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1. Measurement of the Hall coefficient of a given sample and calculation of its
    i. carrier concentration.
2. Measurement of the energy gaps of (i) silicon and (ii) germanium.
3. Measurement of the coercive field and saturation polarization of a ferroelectric
    i. sample.
4. Measurement of the anisotropy of magnetic susceptibility of crystal by (i) Krishnan's method and (ii) Oscillation method.
5. Determination of spin-spin relaxation time of a given sample and the value of the spectroscopic splitting factor (g) by ESR method.
6. Determination of the concentration of color centers in an alkali halides crystal.
7. Study of the characteristics of a photo-diode and calculation of its efficiency of energy conversion.
8. Determination of the value of the lattice parameter and Bravais lattice type of a cubic crystal by Debye-Scherrer method.
9. Obtaining the Laue photograph of a single crystal and drawing gnomonic projections and indexing the spots.
10. Determination of the transverse magneto-resistance coefficient of a given sample and finding the mobility of the carriers.
11. Determination of the cell dimensions of a given single crystal from rotation photograph.

RP -5: Project-II

Final submission of the supervised project and dissertation.

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