Ramakrishna Mission Residential College (Autonomous), Narendrapur

NEW SYLLABUS *for* M.Sc. COURSE *in* PHYSICS (w.e.f. 2015-16 Session)

The course has been divided into 13 theoretical and 7 experimental modules, each of 50 marks.

Total marks: 1000 (Theory : 650, Experiment : 300, Project : 50)

Part I, 1-st Semester :

Theoretical Courses
PAPER – I : Mathematical Methods 50 Marks
PAPER – II : Classical and Relativistic Mechanics 50 Marks
PAPER – III: Quantum Mechanics I 50 Marks

Practical Courses
PAPER – IV : General Practical 1 50 Marks
PAPER – V : General Practical 2 50 Marks

Part I, 2-nd Semester

Theoretical Courses
PAPER – VI : Classical Electrodynamics 50 Marks
PAPER – VII : Quantum Mechanics II 50 Marks
PAPER – VIII: Electronics and Instrumentation 50 Marks

Practical Courses
PAPER – IX : General Practical 3 50 Marks
PAPER – X : Computer Practical 50 Marks

Part II, 3-rd Semester

Theoretical Courses
PAPER – XI : Atomic, Molecular, and Laser Physics 50 Marks
PAPER – XII: Statistical Mechanics 50 Marks
PAPER – XIII: Nuclear and Particle Physics 50 Marks
PAPER – XIV: Condensed Matter Physics 50 Marks

Practical Courses
PAPER – XV : Advanced Experiments I 50 Marks

Part II, 4-th Semester

Theoretical Courses
PAPER – XVI : Advanced Paper I 50 Marks
PAPER – XVII : Advanced Paper II 50 Marks
PAPER – XVIII: Elective Paper 50 Marks

Practical Courses
PAPER – XIX : Advanced Experiments II 50 Marks

PAPER – XX : Projects 50 Marks

Advanced Papers :

PAPER – XVI : Condensed Matter Physics I
PAPER – XVII : Condensed Matter Physics II

Elective Paper (PAPER - XVIII) : Astrophysics

Total number of lectures (including tutorials) for each theoretical paper (50 full marks) is 60.

PAPER – I : Mathematical Methods

1. Complex variables (12)
Recapitulation : Complex numbers, triangular inequalities, Schwarz inequality. Function of a complex variable | single and multiple-valued function, limit and continuity; Differentiation Cauchy-Riemann equations and their applications; Analytic and harmonic function; Complex integrals, Cauchy's theorem (elementary proof only), converse of Cauchy's theorem, Cauchy's Integral Formula and its corollaries; Series | Taylor and Laurent expansion; Classification of singularities; Branch point and branch cut; Residue theorem and evaluation of some typical real integrals using this theorem.

2. Theory of second order linear homogeneous differential equations (6)
Singular points, regular and irregular singular points; Frobenius method; Fuch's theorem; Linear independence of solutions. Wronskian, second solution. Sturm-Liouville theory; Hermitian operators; Completeness.

3. Inhomogeneous differential equations : Green's functions (3)

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

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

6. Vector space and matrices (8)
Vector space: Axiomatic definition, linear independence, bases, dimensionality, inner product; Gram-Schmidt orthogonalisation.
Matrices: Representation of linear transformations and change of base; Eigenvalues and eigenvectors; Functions of a matrix; Cayley-Hamilton theorem; Commuting matrices with degenerate eigenvalues; orthonormality of eigenvectors.

7. Tensors (4)
Basic idea, Applications in various fields of physics.

8. Group theory (10)
Definitions; Multiplication table; Rearrangement theorem; Isomorphism and homomorphism; Illustrations with point symmetry groups; Group representations: faithful and unfaithful representations, reducible and irreducible representations; Lie groups and Lie algebra, product representation of SU(2) and relation with angular momentum.

9. Tutorials (10)

PAPER – II : Classical and Relativistic Mechanics

1. An overview of the Lagrangian formalism (4)
Some specific applications of Lagarange's equation; small oscillations, normal modes and frequencies.

2. Rigid bodies (8)
Independent coordinates; orthogonal transformations and rotations (finite and infinitesimal); Euler's theorem, Euler angles; Inertia tensor and principal axis system; Euler's equations; Heavy symmetrical top with precession and nutation.

3. Hamilton's principle (6)
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.

4. Canonical transformations (8)
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.

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

6. Lagrangian formulation for continuous systems (6)
Lagrangian formulation of acoustic field in gases; the Hamiltonian formulation for continuous systems; Canonical equations from a variational principle, Poisson's brackets and canonical field variables.

7. Classical Chaos (4)
Periodic motions and perturbations; Attractors; Chaotic trajectories and Liapunov exponents; The logistic equation.

8. Special theory of relativity (10)
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 of motion; Relativistic kinematics (decay and elastic scattering); Lagrangian and Hamiltonian of a relativistic particle.

9. Tutorials (10)

PAPER – III : Quantum Mechanics I

1. Recapitulation of Basic Concepts (10)
Wave packet: Gaussian wave packet; Fourier transform; Spreading of a wave packet; Fourier Transforms of delta and sine functions. Coordinate and Momentum space: Coordinate and Momentum representations; x and p in these representations; Parserval's theorem. Eigenvalues and eigenfunctions: Momentum and parity operators; Commutativity and simultaneous eigenfunctions; Complete set of eigenfunctions; expansion of wave function in terms of a complete set. One-dimensional problems: Square well problem ($E > 0$); Delta-function potential; Double-delta potential; Application to molecular inversion; Multiple well potential, Kronig-Penney model.

2. Operator method in Quantum Mechanics (8)
Formulation of Quantum Mechanics in vector space language; Uncertainty principle for two arbitrary operators; One dimensional harmonic oscillator by operator method.

3. Quantum theory of measurement and time evolution (4)
Double Stern-Gerlach experiment for spin-1/2 system; Schrodinger, Heisenberg and interaction pictures.

4. Three-dimensional problems (6)
Three dimensional problems in Cartesian and spherical polar coordinates, 3-d well and Fermi energy; Radial equation of free particle and 3-d harmonic oscillator; Eigenvalue of a 3-d harmonic oscillator by series solution.

5. Angular momentum (6)
Angular momentum algebra; Raising and lowering operators; Matrix representation for $j = 1/2$ and $j = 1$; Spin; Addition of two angular momenta, Clebsch-Gordan coefficients, examples.

6. Approximation Methods (16)
Time independent perturbation theory: First and second order corrections to the energy eigenvalues; First order correction to the eigenvector; Degenerate perturbation theory; Application to one-electron system - Relativistic mass correction, Spin-orbit coupling (L-S and j-j), Zeeman effect and Stark effect. Variational method: He atom as example; First order perturbation; Exchange degeneracy; Ritz principle for excited states for Helium atom.

7. Tutorials (10)

PAPER – IV: Practical (General Experiments – I)

1. **Study of Hall Effect**
2. **Determination of Band-Gap of a Semiconductor**
3. **Study of Iodine Spectra**
4. **Determination of e/m of an electron**
5. **Determination of Planck's Constant**

PAPER – V: Practical (General Experiments – II)

1. **Study of Amplitude Modulation**
2. **Study of Filter Circuits**
3. **Microprocessor – I (Basic Experiments)**
4. **Study of Optical Fiber and determination of Numerical Aperture**

PAPER – VI : Classical Electrodynamics

1. Electrostatics and Magnetostatics (6)
Scalar and vector potentials; Gauge transformations; Multipole expansion of (i) scalar potential and energy due to a static charge distribution (ii) vector potential due to a stationary current distribution. Electrostatic and magnetostatic energy. Poynting's theorem. Maxwell's stress tensor.

2. Radiation from time-dependent sources of charges and currents (6)
Inhomogeneous wave equations and their solutions; Radiation from localised sources and multipole expansion in the radiation zone.

3. Relativistic electrodynamics (15)
Equation of motion in an electromagnetic field; Electromagnetic field tensor, covariance of Maxwell's equations; Maxwell's equations as equations of motion; Lorentz transformation law for the electromagnetic fields and the fields due to a point charge in uniform motion; Field invariants; Covariance of Lorentz force equation and the equation of motion of a charged particle in an electromagnetic field; The generalised momentum; Energy-momentum tensor and the conservation laws for the electromagnetic field; Relativistic Lagrangian and Hamiltonian of a charged particle in an electromagnetic field.

4. Radiation from moving point charges (12)
Lienard-Wiechert potentials; Fields due to a charge moving with uniform velocity; Fields due to an accelerated charge; Radiation at low velocity; Larmor's formula and its relativistic generalisation; Radiation when velocity (relativistic) and acceleration are parallel, Bremsstrahlung; Radiation when velocity and acceleration are perpendicular, Synchrotron radiation; Cherenkov radiation (qualitative treatment only). Thomson and Compton scattering.

5. Radiation reaction (3)
Radiation reaction from energy conservation; Problem with Abraham-Lorentz formula; Limitations of CED.

6. Plasma physics (8)
Definition of plasma; Its occurrence in nature; Dilute and dense plasma; Uniform but time-dependent magnetic field: Magnetic pumping; Static non-uniform magnetic field: Magnetic bottle and loss cone; MHD equations, Magnetic Reynold's number; Pinched plasma; Bennett's relation; Qualitative discussion on sausage and kink instability.

7. Tutorials (10)

PAPER – VII : Quantum Mechanics II

1. WKB Approximation (4)
Quantisation rule, tunnelling through a barrier, qualitative discussion of α-decay.

2. Time-dependent Perturbation Theory (6)
Time dependent perturbation theory, interaction picture; Constant and harmonic perturbations Fermi's Golden rule; Sudden and adiabatic approximations.

3. Scattering theory (12)
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.

4. Symmetries in quantum mechanics (12)
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.

5. Identical Particles (4)
Meaning of identity and consequences; Symmetric and antisymmetric wavefunctions; Slater determinant; Symmetric and antisymmetric spin wavefunctions of two identical particles; Collisions of identical particles.

6. Relativistic Quantum Mechanics (12)
Klein-Gordon equation, Feynman-Stueckelberg 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 matrices; Charge conjugation; Normalisation and completeness of spinors; Lorentz covariance of Dirac equation; Bilinear covariants and their transformation under parity and infinitesimal Lorentz transformation; Weyl representation and chirality projection operators.

7. Tutorials (10)

PAPER – VIII : Electronics and Instrumentation

1. Analog circuits (4)
Comparators, Multivibrators, Waveform generators: Square wave, triangle wave and pulse generators.

2. Digital MOS circuits (8)
NMOS and CMOS gates (AND, NAND and NOT), Dynamic MOS circuits, ratio-inverter, two phase inverter; dynamic MOS shift register, static MOS shift registers, four phase shift registers. Memory Devices; Static and dynamic random access memories (SRAM and DRAM).

3. Transmission line (8)
Transmission line equation and solution; Reflection and transmission coefficient; Standing wave and standing wave ratio; Line impedance and admittance; Smith chart.

4. Physics of Semiconductor devices – I (8)
Carrier concentrations in semiconductors; Band structure of p-n junction; Basic semiconductor equations; p-n diode current voltage characteristics; Dynamic diffusion capacitances; Ebers-Moll equation.

5. Physics of Semiconductor devices – II (10)
Metal semiconductor junctions: Schottky barriers; Rectifying contacts; Ohmic contacts; Typical Schottky barriers. Miscellaneous semiconductor devices: Tunnel diode; Photodiode; Solar cell; LED; LDR; p-n-p-n switch, SCR; Unijunction transistor (UJT); Programmable Unijunction transistor (PUT).

6. Experimental design (8)
Scintillation detectors; Solid state detectors (Si and HPGe).
Measurement of energy and time using electronic signals from the detectors and associated instrumentation, Signal processing; Multi channel analyzer; Time of flight technique; Coincidence measurements true-to-chance ratio.

7. Error analysis and hypothesis testing (4)
Propagation of errors; Plotting of graphs, Distribution, Least square fit, Criteria for goodness of fit ($\chi 2$-testing).

8. Tutorials (10)

PAPER – IX : Practical (General Experiments – III)

1. **Determination of Velocity of Ultrasonic Wave**
2. **Study of S.C.R.**
3. **Microprocessor – II (Advanced Experiments)**
4. **Study of Magneto-resistance**

PAPER – X : Computer Practical (Fortran 90)

1. FORTRAN Language (12)
Constants and variables. Assignment and arithmetic expressions. Logical expressions and control statements, DO loop, array, input and output statements, function subprogram, subroutine.

2. Numerical analysis (12)
Computer arithmetic and errors in floating point representation of numbers, different numerical methods for (i) finding zeroes of a given function, (ii) solution of linear simultaneous equations, (iii) numerical differentiation and integration, (iv) solution of first-order differential equations, (v) interpolation and extrapolation, (vi) least square fitting. Random number generation, sorting.

PAPER – XI : Atomic, Molecular, and Laser Physics

1. One Electron Atom (2)
Introduction: Quantum States; Atomic orbital; Parity of the wave function; Angular and radial distribution functions.

2. Interaction of radiation with matter (6)
Time dependent perturbation: Sinusoidal or constant perturbation; Application of the general equations; Sinusoidal perturbation which couples two discrete states - the resonance phenomenon. Interaction of an atom with electromagnetic wave: The interaction Hamiltonian - Selection rules; Non-resonant excitation, Comparison with the elastically bound electron model; Resonant excitation, Induced absorption and emission.

3. Fine and Hyperfine structure (10)
Solution of Dirac equation in a central field; Relativistic correction to the energy of one electron atom. Fine structure of spectral lines; Selection rules; Lamb shift. Effect of external magnetic field - Strong, moderate and weak field. Hyperfine interaction and isotope shift; Hyperfine splitting of spectral lines; selection rules.

4. Many electron atom (6)
Independent particle model; He atom as an example of central field approximation; Central field approximation for many electron atom; Slater determinant; L-S and j-j coupling; Equivalent and nonequivalent electrons; Energy levels and spectra; Spectroscopic terms; Hund's rule; Lande interval rule; Alkali spectra.

5. Molecular Electronic States (5)
Concept of molecular potential, Separation of electronic and nuclear wavefunctions, Born-Oppenheimer approximation, Electronic states of diatomic molecules, Electronic angular momenta, Approximation methods for the calculation of electronic Wave function, The LCAO approach, States for hydrogen molecular ion, Coulomb, Exchange and Overlap integral, Symmetries of electronic wavefunctions; Shapes of molecular orbital; π and σ - bond; Term symbol for simple molecules.

6. Rotation and Vibration of Molecules (3)
Solution of nuclear equation; Molecular rotation: Non-rigid rotator, Centrifugal distortion, Symmetric top molecules, Molecular vibrations: Harmonic oscillator and the anharmonic oscillator approximation, Morse potential.

7. Spectra of Diatomic Molecules (4)
Transition matrix elements, Vibration-rotation spectra: Pure vibrational transitions, Pure rotational transitions, Vibration-rotation transitions, Electronic transitions: Structure, Franck-Condon principle, Rotational structure of electronic transitions, Fortrat diagram, Dissociation energy of molecules, Continuous spectra, Raman transitions and Raman spectra.

8. Vibration of Polyatomic Molecules: Application of Group Theory (4)
Molecular symmetry; Matrix representation of the symmetry elements of a point group; Reducible and irreducible representations; Character tables for C_{2v} and C_{3v} point groups; Normal coordinates and normal modes; Application of group theory to molecular vibration.

9. Laser Physics (10)
Basic elements of a laser; Threshold condition; Four-level laser system, CW operation of laser; Critical pumping rate; Population inversion and photon number in the cavity around threshold; Output coupling of laser power. Optical resonators; Cavity modes; Mode selection; Pulsed operation of laser: Q-switching and Mode locking; Experimental technique of Q-switching and mode locking Different laser systems: Ruby, CO_2, Dye and Semiconductor diode laser.

10. Tutorials (10)

PAPER – XII : Statistical Mechanics

1. Introduction (8)
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. Boltzmann's postulate of entropy. Counting the number of microstates in phase space. Entropy of ideal gas: Sackur-Tetrode equation and Gibbs' paradox. Liouville's Theorem.

2. Canonical Ensemble (4)
System in contact with a heat reservoir, expression of entropy, canonical partition function, Helmholtz free energy, fluctuation of internal energy.

3. Grand Canonical Ensemble (4)
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.

4. Classical non-ideal gas (4)
Mean field theory and Van der Wall's equation of state; Cluster integrals and Mayer-Ursell expansion.

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

6. Ideal Bose and Fermi gas (6)
Equation of state; Bose condensation; Equation of state of ideal Fermi gas; Fermi gas at finite T.

7. Special topics (10)
Ising model: partition function for one dimensional case; Chemical equilibrium and Saha ionization formula. Phase transitions: first order and continuous, critical exponents and scaling relations. Calculation of exponents from Mean Field Theory and Landau's theory, upper critical dimension.

8. Irreversible Thermodynamics (8)
Flux and afinity. Correlation function of fluctuations. Onsager reciprocity theorem (including proof). Thermoelectric effect.

9. Tutorials (10)

PAPER – XIII : Nuclear and Particle Physics

1. Nuclear Properties (4)
Basic nuclear properties: nuclear size, Rutherford scattering, nuclear radius and charge distribution, nuclear form factor, mass and binding energy, Angular momentum, parity and symmetry, Magnetic dipole moment and electric quadrupole moment, experimental determination, Rabi's method.

2. Two-body bound state (4)
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. Two-body scattering (8)
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 iso-spin invariance of nuclear forces.

4. β-decay (4)
β-emission and electron capture, Fermi's theory of allowed β-decay, Selection rules for Fermi and Gamow-Teller transitions, Parity non-conservation and Wu's experiment.

5. Nuclear Structure (6)
Liquid drop model, Bethe-Weizsacker binding energy/mass formula, Fermi model, Shell model and Collective model.

6. Nuclear Reactions and Fission (10)
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, Super-heavy nuclei.

7. Nuclear Physics in other areas (Qualitative ideas only) (4)
Nuclear Astrophysics: nucleo-synthesis and abundance of elements, neutron star.
Nuclear medicine: diagnostic and therapeutic.

8. Particle Physics (10)
Symmetries and conservation laws, Hadron classification by isospin and hypercharge, SU(2) and SU(3): Groups, algebras and generators; Young tableaux rules for SU(2) and SU(3); Quarks; Colour; Elementary ideas of electroweak interactions and standard model.

9. Tutorials (10)

PAPER – XIV : Solid State Physics

1. Crystal structure (8)
Bravais lattice - primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell; Symmetry operations and classification of 2- and 3-dimensional Bravais lattices; Crystal structures: basis, crystal class, point group and space group (information only); Common crystal structures: NaCl and CsCl structure, crystals of alkali and noble metals, close-packed structure, cubic ZnS structure; Reciprocal lattice and Brillouin zone; Bragg-Laue formulation of X-ray diffraction by a crystal; Atomic and crystal structure factors; Ewald construction; Explanation of experimental methods on the basis of Ewald construction; Electron and neutron diffraction by crystals (qualitative discussion); Intensity of diffraction maxima; Extinctions due to lattice centering; Surface crystallography.
2. Band theory of solids (8)
Limitations of free electron theory; Periodic potential and Bloch's theorem; 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; Energy band in one dimension | reduced zone scheme; E-k diagram in three dimensions - band structures and energy gap; Other methods for calculating band structures. Band structures in Cu, GaAs and Si; Classification of metal, semiconductor and insulator; Topology of Fermi surface - cyclotron resonance; de Haas-van Alphen effect; Boltzmann transport equation relaxation time approximation, electrical conductivity; limitations of Band Theory | metal-insulator transitions.
3. Lattice dynamics and Specific heat (8)
Classical theory of lattice vibration under harmonic approximation; Vibrations of linear monatomic and diatomic lattices, accoustical 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; optical properties of lattice in the infra-red region.
4. Dielectric properties of solids (4)
Complex dielectric constant and dielectric losses, relaxation time and Debye equation for orientational polarizability; Classical theory of electronic and ionic polarization, optical absorption; Ferroelectricity| dipole theory, classifications of ferroelectric material.
5. Magnetic properties of solids (8)
Origin of magnetism; Diamagnetism: quantum theory of atomic diamagnetism; Landau diamagnetism (qualitative discussion); Paramagnetism: quantum theory of paramagnetism; quenching of orbital angular momentum; Van-Vleck paramagnetism and Pauli paramagnetism; Ferromagnetism: Curie-Weiss law, temperature dependence of saturated magnetisation, Heisenberg's exchange interaction, ferromagnetic domains; Ferrimagnetism and antiferromagnetism; Neutron scattering and magnetic structures.
6. Magnetic resonances (3)
Nuclear magnetic resonances, paramagnetic resonance, Bloch equation, longitudinal and transverse relaxation time; Hyperfine field; Electron-spin resonance.
7. Imperfections in solids and optical properties (5)
Frenkel and Schottky defects, defects in growth of crystals; role of dislocations in plastic deformation and crystal growth; Colour centers and photoconductivity; Luminescence and phosphors; Alloys - order-disorder phenomena, Bragg-Williams theory; Extra specific heat in alloys.
8. Superconductivity (6)
Phenomenological description of superconductivity | occurrence of superconductivity, destruction of superconductivity by magnetic field, Meissner effect; Type-I and type-II superconductors; Heat capacity, energy gap and isotope effect; Outlines of the BCS theory; Giaver tunnelling; Flux quantization and Josephson effect.
9. Tutorials (10)

PAPER – XV : Practical (Advanced Experiments – I)

1. **Determination of Lande g - factor**
2. **Study of Lattice Dynamics**
3. **Calibration of Condenser**
4. **Michelson Interferometer**

PAPER – XVI : Advanced – I (Condensed Matter Physics – I)

1. Fundamentals of many-electron system: Hartree-Fock theory (8)
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; the H-F ground state energy.

2. The interacting free-electron gas: Quasi electrons and Plasmon (12)
The H-F approximation of the free electron gas: exchange hole, single-particle energy levels, the ground state energy; Perturbation: theoretical 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 (9)
Absence of magnetism in classical statistics; Origin of the exchange interaction; Direct exchange, superexchange, indirect exchange and itinerant exchange; Spin-waves in ferromagnets - magnons, spontaneous magnetisation, thermodynamics of magnons; Spin-waves in lattices with a basis – ferri and antiferromagnetism; Measurement of magnon spectrum; Ordered magnetism of valence and conduction electrons, the Hubbard Model; Stoners criterion for metalic ferromagnet; Kondo effect.

4. Superconductivity (8)
Electron-electron interaction via lattice: Cooper pairs; BCS theory; Bogoliubov transformation - notion of quasiparticles; Ginzburg-Landau theory and London equation; Meissner effect; Type II superconductors-characteristic length; Josephson effect; “Novel High Temperature" superconductors.

5. Superuidity (5)
Basic phenomenology; λ-Transition and Bose-Einstein condensation; Two fluid model; Roton spectrum and specific heat calculation, Critical velocity.

6. Disordered systems (8)
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.

PAPER – XVII : Advanced –II (Condensed Matter Physics – II)

1. Symmetry in crystals (7)
Concepts of point group; Point groups and Bravais lattices; Crystal symmetry - space groups; Symmetry and degeneracy - crystal field splitting; Kramer's degeneracy; Quasicrystals: general idea, approximate translational and rotational symmetry of two-dimensional Penrose tiling, Frank-Casper phase in metallic glass.

2. Lattice dynamics (12)
Classical theory of lattice vibrations in 3-dimensions under harmonic approximation; Dispersion relation: accoustical 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 occupation number representation; Thermal conductivity in insulators.

3. Density Functional Theory (8)
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.

4. Electronic properties - I (8)
The Boltzmann transport equation and relaxation time; Electrical conductivity of metals- impurity scattering, ideal resistance at high and low temperatures, U-processes; Thermo-electric effects; Thermal conductivity; The Wiedemann-Franz law.

5. Electronic properties-II (8)
Electronic properties in a magnetic field; Classical theory of magneto-resistance; Hall effect and magneto-resistance in two-band model; K-space analysis of electron motion in a uniform magnetic field; Idea of closed, open and extended orbits, cyclotron resonance; Azbel-Kaner resonance; Energy levels and density of states in a magnetic field; Landau diamagnetism; de Haas-van Alphen effect; Quantum Hall effect.

6. Optical properties of solids (7)
The dielectric function: the dielectric function for a harmonic oscillator, dielctric losses of electrons, Kramers-Kronig relations; Interaction of phonons and electrons with photons; Interband transition - direct and indirect transition; Absorption in insulators; Polaritons; One-phonon absorption; Optical properties of metals, skin effect and anomalous skin effect.

PAPER – XVIII : Elective Paper (Astrophysics)

1. Basic Background and Instrumentation (6)
Elementary radiative transfer equations, absorption and emission, atomic processes, continuum and line emission; Optical and radio telescopes, Fourier transform methods, detectors and image processing; Distance measurements in astronomy, Hubbles law; Modern observational techniques (qualitative discussion only).

2. Spectral Classification of Stars (3)
Saha's equation; Harvard system, luminosity effect; Absolute and apparent luminosity; Mass luminosity relation, spectroscopic parallax.

3. Evolution of Stars (14)
Observational basis, protostars, disks, bipolar outflows, hydrostatic equilibrium; Sources of stellar energy: gravitational collapse, fusion reactions (p-p chain, CNO cycle, triple α reactions); formation of heavy elements; Hertzsprung-Russell diagram, evolution of low-mass and high-mass stars; Chandrasekhar limit; Pulsars, neutron stars, and black holes.

4. Elements of General Relativity (12)
Curved space-time; Eotvos experiment and the equivalence principle; Equation of geodesic; Christoffel symbols; Schwarzschild geometry and black holes; FRW geometry and the expanding universe; Riemann curvature; Einstein equations.

5. Binary Stars (3)
Different types of binary stars; Importance of binary systems; Accretion; Gravitational radiation.

6. Cosmic Astrophysics (12)
Important models of the universe; Red shift and expansion; Big bang theory; Early universe and decoupling; Neutrino temperature, nucleo-synthesis, relative abundances of hydrogen, helium, deuterium; Radiation and matter-dominated phases; Cosmic microwave background radiation, its isotropy and anisotropy properties; COBE and WMAP experiments; CMBR anisotropy as a hint to large scale structure formation.

PAPER – XIX : Practical (Advanced Experiments – II)

1. **Study of Hall Effect at elevated temperatures**
2. **Study of Dielectric constant and determination of Curie temperature**
3. **Study of P-N junction at elevated temperatures**
4. **X-ray diffraction :** Debye-Scherrer and Laue photographs.

Text & Reference Books :

PAPER – I : Mathematical Methods

1. G. Arfken: Mathematical Methods for Physicists
2. J. Mathews and R.L. Walker : Mathematical Methods of Physics
3. P.K. Chattopadhyay: Mathematical Physics
4. R.V. Churchill and J.W. Brown: Complex variables and Applications
5. M.R. Spiegel: Theory and Problems of Complex Variables
6. W.W. Bell: Special Functions for Scientists and Engineers
7. A.W. Joshi: Matrices and Tensors in Physics
8. A.W. Joshi: Elements of Group Theory for Physicists
9. M. Tinkham: Group Theory and Quantum Mechanics

PAPER – II : Classical and Relativistic Mechanics

1. H. Goldstein: Classical Mechanics
2. K.C. Gupta: Classical Mechanics of Particles and Rigid Bodies
3. S.N. Biswas: Classical Mechanics
4. N.C. Rana and P.S. Joag: Classical Mechanics
5. A.P. French: Special Relativity

PAPER – III : Quantum Mechanics I

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