

**SYLLABUS FOR M.Sc. COURSE IN  
PHYSICS**

**UNIVERSITY OF CALCUTTA**

**2015**

## Syllabus for the M.Sc. course in Physics University of Calcutta

The structure of the revised syllabus for the M.Sc. course in Physics, applicable from the academic year 2015-16, is suggested to be as follows.

### Part 1, 1st Semester

Theoretical Courses		
PHY 411	Mathematical Methods	50 Marks
PHY 412	Classical and Relativistic Mechanics	50 Marks
PHY 413	Quantum Mechanics I	50 Marks
Practical Courses		
PHY 414	General Practical 1	50 Marks
PHY 415	General Practical 2	50 Marks

### Part 1, 2nd Semester

Theoretical Courses		
PHY 421	Classical Electrodynamics	50 Marks
PHY 422	Quantum Mechanics II	50 Marks
PHY 423	Electronics and Instrumentation	50 Marks
Practical Courses		
PHY 424	General Practical 3	50 Marks
PHY 425	Computer Practical	50 Marks

### Part 2, 3rd Semester

Theoretical Courses		
PHY 511	Atomic, Molecular, and Laser Physics	50 Marks
PHY 512	Statistical Mechanics	50 Marks
PHY 513	Nuclear and Particle Physics	50 Marks
PHY 514	Solid State Physics	50 Marks
Practical Courses		
PHY 515	Advanced Experiments I	50 Marks

### Part 2, 4th Semester

Theoretical Courses		
PHY 521	Advanced Paper I	50 Marks
PHY 522	Advanced Paper II	50 Marks
PHY 523	Advanced Paper III	50 Marks
Practical Courses		
PHY 524	Comprehensive Competence	50 Marks
PHY 525	Advanced Experiments II	50 Marks

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

**Total marks: 1000, Theory: 650, Experiment: 350**

To have the M.Sc. degree, a student must pass in all the modules. To pass in a module, a student must get at least 40% marks. A student failing to secure 40% marks in more than two modules in a semester shall be deemed to have failed in that semester and shall not be allowed to proceed in the next semester; (s)he shall appear at the subsequent examination for that semester in all the modules

The general experiments PHY 414, PHY 415, and PHY 424 will have a common syllabus as a pool of experiments. A similar pattern will follow for PHY 515 and PHY 525, as a pool of advanced experiments. PHY 524 will have a written part based on the compulsory theoretical courses and a comprehensive viva.

**Teaching period:** Should be 14 weeks for each semester, followed by a study leave of about 3 weeks.

For Physics M.Sc. students, all modules except PHY 521 and PHY 523 must be taken in the department. For some choices of PHY 522, PHY 521 is fixed and must also be taken in the department. The open modules can be taken from courses (related to Physics and to be approved by the DC of the Physics department) offered by other departments of this university.

Students of other departments of this university can attend any theoretical course, provided the respective department permits.

**Advanced Papers:** Some of the following topics may be offered as Advanced papers. New topics may be added to the list from time to time.

**Advanced I Papers (PHY 521)**

1. Condensed Matter Physics I
2. Nuclear Structure
3. Quantum Electronics
4. Quantum Field Theory

**Advanced II Papers (PHY 522)**

1. Condensed Matter Physics II
2. Laser Physics
3. Materials Physics
4. Nuclear Reaction and Nuclear Astrophysics
5. Particle Physics
6. Solid State Electronics
7. Advanced Statistical Physics and its Applications

**Advanced III Papers (PHY 523)**

1. Astrophysics and Cosmology
2. General Theory of Relativity
3. Physics of Microwaves
4. Nonlinear Dynamics
5. Soft Matter Physics

Total number of lectures (plus tutorials) for theoretical papers is 60 for each unit of 50 marks (core courses: PHY 411, PHY 412, PHY 413, PHY 421, PHY 422, PHY 512) and 50 for each unit of 50 marks (applied courses: rest)

## PHY 411: Mathematical Methods

### 1. Vector space and matrices (7)

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.

### 2. 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 with  $SU(2)$  as an example.

### 3. Complex analysis (13)

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.

### 4. 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.

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

### 6. Special functions (3)

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

### 7. Integral transforms (3)

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.

### 8. Tutorials (15)

## PHY 412: Classical and Relativistic Mechanics

### 1. An overview of the Lagrangian formalism (5)

Some specific applications of Lagrange's equation; small oscillations, normal modes and frequencies.

### 2. 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.

### 3. Canonical transformations (6)

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.

### 4. Hamilton-Jacobi theory (4)

The Hamilton Jacobi equation for Hamilton's principle function; The harmonic oscillator problem; Hamilton's characteristic function; Action angle variables.

### 5. 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.

## 6. Elements of Fluid Mechanics and Navier -Stokes Equation (4)

## 7. Introduction to Chaos (4)

Periodic motions and perturbations; Attractors; Chaotic trajectories and Liapunov exponents; The logistic equation.

## 8. Special theory of relativity (8)

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 (15)

### PHY 413: Quantum Mechanics I

## 1. Recapitulation of Basic Concepts (9)

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 (3)

Double Stern-Gerlach experiment for spin- $\frac{1}{2}$  system; Schrödinger, Heisenberg and interaction pictures.

## 4. Three-dimensional problems (5)

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  $j = \frac{1}{2}$  and  $j = 1$ ; Spin; Addition of two angular momenta — Clebsch-Gordan coefficients, examples.

## 6. Approximation Methods (14)

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 (15)

### PHY 421: 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 (5)**  
Inhomogeneous wave equations and their solutions; Radiation from localised sources and multipole expansion in the radiation zone.
3. **Lagrangian formulation for continuous systems and Relativistic electrodynamics (13)**  
Idea of a classical field as a generalised coordinate. Euler-Lagrange equation for the field from the Lagrangian density. The field momentum and the Hamiltonian density. Poisson brackets for the fields. 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 (6)**  
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 (15)**

## PHY 422: Quantum Mechanics II

1. **WKB Approximation (3)**  
Quantisation rule, tunnelling through a barrier, qualitative discussion of  $\alpha$ -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  $j = \frac{1}{2}$  and  $j = 1$ ; Rotation matrices; Irreducible spherical tensor operators, Wigner-Eckart theorem; Discrete symmetries — parity and time reversal.
5. **Identical Particles (3)**  
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 (9)**  
Klein-Gordon equation, Feynman-Stückelberg interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum

space spinors; Spin and magnetic moment of the electron; Non-relativistic reduction; Helicity and chirality; Properties of  $\gamma$  matrices; Charge conjugation; Normalisation and completeness of spinors.

## 7. Tutorials (15)

### PHY 423: Electronics and Instrumentation

#### 1. Power Circuits (5)

Series-fed class A power amplifier; Harmonic distortion; Higher harmonic generation; Transformer coupled power amplifier; Class B power amplifier; Crossover distortion; Class AB operation, Class C operation.

#### 2. Filters (5)

Passive filters: Propagation constant; Constant-K low pass and high pass filters; Active filters: Butterworth filter, low pass and high pass filters; Butterworth polynomials; RC bandpass filter; Bandreject Filter; Delay equalizer.

#### 3. Digital MOS circuits (5)

NMOS and CMOS gates (AND, NAND and NOT), Dynamic MOS circuits, MOS shift register, Memory Devices; Random access memory (RAM), Static and dynamic random access memories (SRAM and DRAM)

#### 4. Transmission line (9)

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

#### 5. Physics of Semiconductor devices I (8)

Carrier concentrations in semiconductors; Band structure of p-n junction; Current flow in a semiconductor-A drift current and diffusion current; Basic semiconductor equations; p-n diode current voltage characteristics; Dynamic diffusion capacitances; Ebers-Moll equation.

#### 6. Physics of Semiconductor devices II (8)

Metal semiconductor junctions: Schottky barriers; Rectifying contacts; Ohmic contacts; Typical Schottky barriers. Miscellaneous semiconductor devices: Tunnel diode; Photodiode; Solar cell; LED; LDR.

#### 7. Experimental Design and Error Analysis (10)

Scintillation detectors; Solid state detectors (Si and HPGc). 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; Lock-in detection technique; Propagation of errors, Distribution, Least square fit, Criteria for goodness of fit.

Production and measurement of high vacuum: Rotary pump, Diffusion pump, Turbomolecular pump, Ion pump; McLeod gauge, Pirani gauge, Penning gauge.

### PHY 511: 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; Nonresonant 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;  $\pi$  and  $\sigma$  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;

### PHY 512: Statistical Mechanics

1. **Introduction (6)**  
Objective of statistical mechanics. Central Limit Theorem. 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 (3)**  
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. Chemical equilibrium and Saha Ionisation Equation.
4. **Classical non-ideal gas (4)**  
Mean field theory and Van der Waals' equation of state; Cluster integrals and Mayer-Ursell expansion.
5. **Quantum statistical mechanics (5)**  
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. Phase Transition and Critical Phenomena (9)**

Ising model – partition function for one dimensional case; Chemical equilibrium and Saha ionisation 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, Rudiments of Real Space Renormalisation Group Transformations.

**8. Non-equilibrium Statistical Mechanics (8)**

Irreversible processes, Classical Linear Response Theory, Brownian Motion, Master Equation, Fokker-Planck Equation, Fluctuation-Dissipation Theorem

**9. Tutorials (5)**

**PHY 513: 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 (3)**

Properties of deuteron, Schrödinger 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 (6)**

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

**4. Nuclear structure (7)**

Liquid drop model, Bethe-Weizsäcker binding energy/mass formula, Fermi model, Shell model and Collective model,  $\gamma$ -decay.

**5. 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. Elementary ideas about astrophysical reactions, Nucleosynthesis and abundance of elements.

**6.  $\beta$ -decay and weak interaction (8)**

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

**7. Strong interaction (7)**

Symmetries and conservation laws, Hadron classification by isospin and hypercharge, SU(3) algebra; Young tableaux rules for SU(3); Quarks; Colour; Gell-Mann – Okubo mass relation. Magnetic moment of hadrons.

**8. Electroweak theory (2)**

Elementary ideas of electroweak unification and Standard Model.

**9. Big bang nucleosynthesis (3)**

Qualitative idea of BBN, relative abundances of hydrogen, helium, and deuterium.

**PHY 514 Solid State Physics**

**1. Structure of solids (9)**

Bravais lattice, primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell; Symmetry operations and classification of 2- and 3-dimensional Bravais lattices; point group and space group (information only); Common crystal structures: NaCl and CsCl structure, close-packed structure, Zinc blende and Wurtzite structure, tetrahedral and octahedral interstitial sites, Spinel structure; Intensity of scattered X-ray, Friedel's law, Anomalous scattering; Atomic and geometric structure factors; systematic absences; Reciprocal lattice and Brillouin zone; Ewald construction; Explanation of experimental methods on the basis of Ewald construction; Electron and neutron scattering by crystals (qualitative discussion); Surface crystallography; Graphene; Real space analysis — HRTEM, STM, FIM. Non crystalline solids — Monatomic amorphous materials; Radial distribution function; Structure of vitreous silica.

**2. Band theory of solids (6)**

Bloch equation; Empty lattice band; Number of states in a band; Effective mass of an electron in a band: concept of holes; Classification of metal, semiconductor and insulator; Electronic band structures in solids - Nearly free electron bands; Tight binding method - application to a simple cubic lattice; Band structures in copper, GaAs and silicon; Topology of Fermi-surface; Quantization of orbits in a magnetic field, cyclotron resonance — de Haas-van Alphen effect; Boltzmann transport equation - relaxation time approximation, Sommerfeld theory of electrical conductivity.

**3. Lattice dynamics and Specific heat (6)**

Classical theory of lattice vibration under harmonic approximation; Dispersion relations of one dimension lattices: monatomic and diatomic cases, Characteristics of different modes, long wavelength limit, Optical properties of ionic crystal in the infrared region; 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.

**4. Dielectric properties of solids (6)**

Electronic, ionic, and orientational polarization; static dielectric constant of gases and solids; Complex dielectric constant and dielectric losses, relaxation time, Debye equations; Cases of distribution of relaxation time, Cole - Cole distribution parameter, Dielectric modulus; Ferroelectricity, displacive phase transition, Landau Theory of Phase Transition.

**5. Magnetic properties of solids (9)**

Origin of magnetism; Diamagnetism: quantum theory of atomic diamagnetism; Landau diamagnetism (qualitative discussion); Paramagnetism: classical and quantum theory of paramagnetism; case of rare-earth and iron-group ions; 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 - calculation of wall thickness and energy; Ferrimagnetism and antiferromagnetism.

**6. Magnetic resonances (4)**

Nuclear magnetic resonances, paramagnetic resonance, Bloch equation, longitudinal and transverse relaxation time; spin echo; motional narrowing in line width; absorption and dispersion; Hyperfine field; Electron-spin resonance.

**7. Imperfections in solids (6)**

Frenkel and Schottky defects, defects by non stoichiometry; electrical conductivity of ionic crystals; classifications of dislocations; role of dislocations in plastic deformation and crystal growth; Colour centers and photoconductivity; Luminescence and phosphors; Alloys, Hume-Rothery rules; electron compounds; Bragg - Williams theory, order-disorder phenomena, superstructure lines; 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; Giaever tunnelling; Flux quantisation; a.c. and d.c. Josephson effect; Vortex state (qualitative discussions); High  $T_c$  superconductors (information only).

**PHY 521: 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, Koopman's 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 (8)**  
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.
3. **Spin-spin interaction: Magnons (8)**  
Absence of magnetism in classical statistics; Origin of the exchange interaction; Direct exchange, super exchange, indirect exchange and itinerant exchange; Spin-waves in ferromagnets and antiferromagnets (semi classical and quantum treatment using Holstein Primakoff transformation), spontaneous symmetry breaking in magnetic systems with continuous symmetry, thermodynamics of magnons, mean field theory and critical behaviour for large S models.
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. **Superfluidity (5)**  
Basic Phenomenology; 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; mobility edge; Minimum Metallic Conductivity, Qualitative application of the idea to amorphous semiconductors and hopping conduction. Percolation phenomena and the associated phase transition properties.
7. **Selected topics (5)**  
Mott transition, Stoners criterion for metallic ferromagnet. Elementary introduction to Hubbard Model, Kondo effect. ‘

**Nuclear Structure**

1. **Nuclear Models (25)**
  - (a) Nuclear shell model: Individual particle model, Basic idea of an actual calculation (seniority scheme, qualitative discussion of cfp, diagonalization).
  - (b) Collective model (especially for odd-A nuclei): Coupling of particle and collective motions, Ground state,  $\beta$  and  $\gamma$  bands (rotational).
  - (c) Phenomenological description of collective degrees of excitations, VMI and anharmonic vibrator models, Behaviour of nuclei at high-spin.
  - (d) Nilsson model.
  - (e) Nuclei far away from the stability valley: Drip line, Extremely neutron rich nuclei, Superheavy nuclei.

2. **Microscopic theory (11)**  
Occupation number representation, Creation and annihilation operators, One and two-body operators, Matrix elements, Wick's theorem.  
Hartree-Fock approximation and HF equations. BCS model.
3.  **$\gamma$ -decay (8)**  
Interaction of electromagnetic field with nuclei, Multipole expansion, Parity and angular momentum selection rules, Transition probability within single particle model, Angular distribution and directional correlation orientation ratio.
4. **Quark degrees of freedom (6)**  
Introduction to quark degrees of freedom, Basic idea of confinement, Phenomenological Bag model, Bag model at finite temperature and equation of state.

## Quantum Electronics

1. **Semiconductor Laser (6)**  
Homojunction laser: Population inversion at a junction; Emission spectra; The basic semiconductor laser;  
Heterojunction: Formation of ideal heterojunctions between (a) a p-type wide band-gap semiconductor and an n-type narrower band-gap semiconductor, (b) an n-type wide band-gap semiconductor and a p-type narrower band-gap semiconductor, (c) wide and lightly doped narrower band gap n-type semiconductors; Anderson's model of ideal heterojunction.  
Heterojunction laser: Single and double heterojunction laser; Analysis of carrier confinement in a single heterojunction laser.
2. **Electrons in quantum structures (6)**  
Energy level and wave functions for quantum well, quantum wire and quantum dot; Density of states for quantum well, quantum wire and quantum dot; Modulation — doped quantum well; Multiple quantum well; Coupling between quantum wells.  
Super lattice: The concept of a super lattice; Krönig-Penney model of a super lattice — zone folding, Tight binding approximation for a super lattice.
3. **Quantum Semiconductor Laser (3)**  
Light amplification in quantum well; Modulation bandwidth; Strained quantum well laser; Quantum wire laser; Blue quantum well laser.
4. **Electro-optic effect in quantum structures (3)**  
Franz-Keldysh effect in Semiconductor; Electro-optic effect in quantum wells; Electro-optic effect in super lattice.
5. **Parallel and Perpendicular Transport in Quantum Structures (6)**  
High field electron transport — Hot electrons in quantum structures; Double barrier resonant-tunneling structures; Super lattices and ballistic injection devices.
6. **Quantum Transistor (6)**  
Resonant-tunneling unipolar and bipolar transistor; Velocity modulation and quantum interference transistor.
7. **Guided wave optics (5)**
  - (a) Waveguide modes, Modes characteristics for a planar waveguide, Step index planar waveguide, Maxwell equations in inhomogeneous media: TE modes and TM modes, Radiation modes, Guided modes, Leaky modes, Quasi modes.
  - (b) Propagation in optical fibre, Numerical aperture, Pulse dispersion in fibres, Scalar wave equation and modes of the fibre, Modal analysis for a step index fibre.
8. **Masers (3)**  
Ammonia beam maser, Energy levels, Methods for population inversion, Maser operation.
9. **Coherent interactions of a radiation field and an atomic system (5)**
  - (a) Induced resonant transitions, Inclusions of decay phenomena, Rotating wave approximation, Exact Rabi Solution in the strong field, Rabi flopping,  $\pi$ -pulse, Dressed state picture.
  - (b) Density matrix, Rate equation for density matrix, Optical Bloch equations, Vector model of density matrix, The Bloch sphere.

10. **Semiclassical laser theory (7)**

Electromagnetic field equations, Expansion in normal modes of a cavity, Lamb's self-consistency equations, Density matrix equations, Polarization of the medium, Single mode operation, Non-linear effect in polarization, Hole burning, Steady state power, Frequency pulling and pushing.

### Quantum Field Theory

1. **Lorentz Group (5)**

Continuous and discrete transformations, Group structure, Proper and improper Lorentz Transformations,  $SL(2,C)$  representations, Poincare group.

2. **Canonical quantization of free fields (9)**

Real and complex scalar fields, Dirac field, electromagnetic field, Bilinear covariants, Projection operators, Charge conjugation and Parity on scalar, Dirac and electromagnetic fields.

3. **Interacting fields (6)**

Interaction picture, Covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagrams.

4. **QED (9)**

Feynman rules, Example of actual calculations: Rutherford, Bhabha, Moeller, Compton,  $e^+e^- \rightarrow \mu^+\mu^-$ . Decay and scattering kinematics. Mandelstam variables and use of crossing symmetry.

5. **Higher order corrections (6)**

One-loop diagrams. Basic idea of regularization and renormalization. Degree of divergence. Calculation of self-energy of scalar in  $\phi^4$  theory using cut-off or dimensional regularization.

6. **Gauge theories (10)**

Gauge invariance in QED, non-abelian gauge theories, QCD (introduction), Asymptotic freedom, Spontaneous symmetry breaking, Higgs mechanism.

### PHY 522: Advanced II Condensed Matter Physics II

1. **Symmetry in crystals (9)**

Concepts of point group; Point groups and Bravais lattices; Crystal symmetry space groups; Symmetry and degeneracy - crystal field splitting; Kramer's degeneracy; incommensurate structure; Quasicrystals: general idea, Fibonacci lattice, Higher dimensional space, approximate translational and rotational symmetry of two-dimensional Penrose tiling, Diffraction from Fibonacci lattice, Frank-Casper phase in metallic glass.

2. **Lattice dynamics (10)**

Classical theory of lattice vibrations in 3-dimensions under harmonic approximation; Dispersion relation: acoustical and optical, transverse and longitudinal modes; Lattice vibrations in a monatomic simple cubic lattice; Symmetry consideration of eigen vectors; Frequency distribution function; Maxima, minima and Saddle points; Frequency variation close to the critical points, Normal coordinates and phonons; Occupation number representation of the lattice Hamiltonian, Phonon-phonon interaction; Neutron diffraction by lattice vibrations; Coherent and incoherent scattering, scattering cross section for one phonon, multi-phonon processes, Debye - Waller factor; Atomic displacement and melting point; Thermal conductivity in insulators; Mossbauer effect.

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 (6)**

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 (7)**

Electronic properties in a magnetic field; Classical theory of magneto-resistance; Hall effect and magnetoresistance in two-band model; K-space analysis of electron motion in a uniform magnetic field;

magnetoresistance for open 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 (10)**

Kramers - Kronig relations; Sum rules, Dielectric function for ionic lattice, Polariton dispersion, Soft mode and Ferroelectricity, Dielectric function for free electron gas; loss spectroscopy, optical properties of metals, skin effect and anomalous skin effect, Free carrier absorption in semiconductor; Interband transition - direct and indirect transition, surface and interface modes.

## **Laser Physics**

### 1. **Laser Spectroscopy (15)**

Physical Effects of Strong Fields on Atomic Matter: Basic concepts of light-induced effects on atomic matter, Inclusion of phenomenological aspects of population and depopulation in a two-level system. A stationary two-level atom in a standing wave, A moving two-level atom in traveling wave, A moving two-level atom in a standing wave, Lamb dip, Saturation phenomena, Hole burning, Physical significance, Three-level systems with two laser fields: concepts and approach.

### 2. **Quantization of the radiation field (10)**

Background and importance, Lamb shift Classical electromagnetic field, Free classical field, Quantization of electromagnetic field, Photon number states and eigenvalues, Significance of creation/annihilation operators and electric field operator. Multimode electromagnetic field. Interaction picture, Atom-field interactions (first-order perturbation theory and Rabi solution), spontaneous emission, stimulated absorption and emission, Wigner-Weiskopf theory of spontaneous emission.

### 3. **Optical fluctuations and Coherence (4)**

Coherent light: Poissonian photon statistics, Super-Poissonian light: Thermal light and chaotic light, Sub-Poissonian light. Photon antibunching: Mach-Zehnder interferometer, First-order coherence, The intensity interferometer, Hanbury-Brown Twiss experiments, Second order coherence, Photon bunching and antibunching, Coherent light, Bunched light, Antibunched light.

### 4. **Nonlinear interactions of light and matter (7)**

Nonlinear polarization of the medium, Optical susceptibility tensor, Generation of second harmonic, Sum frequency and difference frequency generation, Optical rectification, Parametric amplifier and oscillation, Generation of third harmonic, Intensity dependent refractive index, Self-focussing, Wave equation for nonlinear optical media, Coupled wave equation for sum frequency generation, Phase matching considerations.

### 5. **Mechanical effects of light (4)**

Dynamics of an atom in a laser field, Light forces on atoms, Radiation pressure force, Dipole force, Optical potential.

### 6. **Laser Cooling, Trapping and Bose-Einstein Condensation (10)**

Doppler cooling, Cooling of an atomic beam, Optical molasses, Doppler cooling limit, Sub-Doppler cooling: Sisyphus cooling, Recoil cooling limit, Magneto-optic trap, Magnetic trap, Quadrupole trap, Optical trap, Experimental techniques.

Theoretical overview of Bose-Einstein Condensate, Experimental realization, Evaporative cooling, Observation of condensate.

## **Materials Physics**

### 1. **Physical properties of materials (6)**

Tensor Properties of Materials; Tensor representation of electrical and thermal conductivity, Onsager's principle, heat flow in crystals; Stress and Strain – effect of crystal symmetry; Thermoelectric effect in crystals; Thermal expansion; Magnetic susceptibility; The Hall effect – axial third rank tensor, relationship to symmetry, Magnetoresistance, Kubo Greenwood formalism.

### 2. **Phase transition in materials (9)**

Thermodynamics and phase diagrams: Kinetics vs. thermodynamics: Role of interface energy. Interfacial coherency and the shape of precipitates. The effect of interfacial curvature on equilibrium-Grain growth, Ostwald ripening. Surface energy and nanostructured materials. Diffusion in solids: activation energies and fast diffusion paths, Variation of diffusion constant with temperature. Ficks 2nd

law: specific solutions to time dependent diffusion problems. Diffusion in substitutional alloys: Kirkendall effect; Homogeneous and heterogeneous nucleation; Interface controlled vs. diffusion controlled growth, Rate laws for different growth geometries and coarsening – Avrami Equation. Diffusionless transformations: Ordering, recrystallization, the martensite transformation (basics only). Spinodal decomposition: Spinodal curve, Free energy of compositional fluctuations, Kinetics of Spinodal decomposition.

### 3. Magneto-resistance and its application (6)

Ordinary and anisotropic magneto-resistance, mechanism; Giant magneto-resistance (GMR): basic properties, mechanism, Application — spin valves and spin switches; Colossal magneto-resistance (CMR): basic properties and phase diagram, comparison with GMR; structure-tolerance factor, effect of doping, charge ordering; Theoretical understanding – Double exchange mechanism, crystal field splitting and Jahn-Teller distortion, electron phonon coupling, Recent developments; Application – Magnetoresistive devices

### 4. Exotic solids (9)

Aperiodic solids and Quasicrystals, Fibonacci sequence, Penrose lattices and their extensions in 3 dimensions; Special carbon solids: Fullerene, Graphene and Carbon Nano Tube – Structure, formation and characterization; Synthesis; Density of States, Elementary electronic properties and band structure; Usual properties of Graphene – Dirac Fermion, single wall and multiwall carbon nanotube, Carbon nanotubule based electronic devices.

### 5. Computational methods in Materials Physics (10)

*Quantum mechanical modeling of materials:* Hartree Fock and Density Functional Theory. Atomic Pseudopotentials, Basis Sets: Plane Waves and Augmented Basis sets. Plane Wave based DFT calculations. Simplified Approaches to the electronic problem: Tight binding methods;  
*Atomistic modeling of materials:* Many body Classical potentials, Classical force fields. Monte Carlo and Molecular dynamics simulations;  
Hybrid Quantum Mechanics Molecular Mechanics (QM-MM) method. Car-Parrinello molecular dynamics.

### 6. Experimental characterization techniques (10)

Structure: X-ray diffraction (XRD) patterns, Intensities of reflections, Thermal effects on diffraction patterns, Identification of phases, Effects of disorder, Strain and crystallite size;  
Morphology: Scanning electron microscopy (SEM), Energy-dispersive and wavelength – dispersive spectrometry; Transmission electron microscopy (TEM), Selected area diffraction patterns, Diffraction contrast to image defects;  
Defect: Positron annihilation lifetime spectroscopy, defect analysis from PAL spectroscopy, defect property correlation.

## Nuclear Reaction and Nuclear Astrophysics

### 1. Nuclear Reactions

- (a) Introduction: Survey of reactions of nuclei (2): Strong, electromagnetic and weak processes, Types of reactions and Q-values, Reaction mechanisms: Energy and time scales for direct and compound reactions, Experimental observables: Cross sections — definitions and units; Angular distributions, Excitation functions,
- (b) Models for nuclear reactions (8): Direct reactions: Optical Model: From Hamiltonian to cross sections for elastic scattering; Partial waves, Phase shifts, Scattering amplitudes, S-matrix and its symmetry and reciprocity; Angular distributions, Optical potential.  
Green functions methods: T-matrix expression, Two potential formula, Plane-wave and distorted-wave Born series.  
Connection with nuclear structure: Reference to folded potential, Nuclear density, Inelastic excitation, Electric B ( $E_k$ ) and nuclear deformations, transfer reactions, Spectroscopic factors, Asymptotic normalization constant (ANC).  
Compound nuclear reactions : Statistical model.  
R-matrix methods: Dispersion theory, One level formula.

- (c) Heavy Ion collisions (6): Collisions near the Coulomb barrier: Semiclassical concepts, Elastic scattering, Coulomb excitation, Deep inelastic collisions, Fusion, Collisions near the Fermi velocity, Collisions near the speed of light: Classifications of reactions and products. Ultra relativistic nuclear collisions: Phase diagram of nuclear matter.
- (d) Nuclear Fission (4): Spontaneous fission, Mass energy distribution of fission fragments, Bohr-Wheeler theory, Fission isobars, Super-heavy nuclei.
- (e) Reactions involving exotic nuclei (1)

## 2. Nuclear Astrophysics

- (a) Thermonuclear reactions (5): Reaction rates. Low energy behaviour and astrophysical S-factors, Forward and reverse reactions, Nonresonant and resonant reactions, Maxwell-Boltzmann distribution of velocities, Gamow peak.
- (b) Big Bang nucleosynthesis (3): He production, Be bottleneck, Abundance of light elements.
- (c) Stellar structure (3): Classical stars, Degenerate stars.
- (d) Nuclear burning in stars (6): H burning, He burning, Advanced nuclear burning, Core collapse.
- (e) Stellar nucleosynthesis (4): Abundance of elements, Production of nuclei, r-, s- and  $\gamma$ -processes.

## 3. Experimental techniques (8)

Experimental signature of different nuclear reactions: compound nucleus and direct reaction. Charged particle: detection and identification using particle telescope and time of flight measurement, neutron detection using pulse shape discrimination technique,  $\gamma$ -ray detection: different detector characteristics, evaluation of level structure, lifetime measurement, polarization measurement.

## Particle Physics

### 1. Hadron structure and QCD (15)

Elastic e-p scattering, electromagnetic form factors, electron-hadron DIS, structure functions, scaling, sum rules, neutrino production, jet production in  $e^+e^-$  collision, scaling violation.

### 2. Low energy weak interactions (5)

Fermi theory, calculation of decay widths of muon and  $\pi^+$ .

### 3. Electroweak Theory (9)

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

### 4. Flavour physics (8)

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

### 5. Neutrino physics (6)

Theory of two-flavour oscillation. Solar and atmospheric neutrino anomalies. Neutrino experiments. The India-based Neutrino Observatory.

### 6. HEP experiments (2)

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

## Solid State Electronics

### 1. Foundation of Solid State Electronics (8)

Boltzmann Transport Equation, expressions for mobility and diffusion constant, Einstein relation, temperature dependence of mobility, negative differential mobility; magnetotransport - Hall coefficient and magnetoresistance, Quantum Hall effect; recombination of electron hole pairs: Direct recombination, Kinetics of traps and recombination centers; surface states, pinning of Fermi level; continuity equations, space charge in semiconductors, relaxation effects; space charge neutrality, ambipolar effects; experimental determination of mobility, diffusion constant and lifetime of minority carriers, Hayens Shockley experiment.



## 2. Semiconductor Technology (5)

Preparation of semiconductor materials: different crystal growth methods, epitaxial growth, strain for lattice mismatch, effect of strain on band structure, pseudomorphic layer, heterostructures, synthesis - Molecular beam epitaxy; metal organic chemical vapor deposition; kinetics of growth; oxidation; diffusion and ion implantation process.

## 3. JFET and MESFET (5)

Family tree of FET: Basic device characteristics of FET- uniform charge distribution, arbitrary charge distribution, General characteristics- field dependent mobility, two region model and saturated velocity model, microwave performance, related field effect devices.

## 4. MOSFET and CCD (8)

Surface charge in MOS-capacitors; Capacitance voltage characteristics of MIS structure; Basic device characteristics, Non-equilibrium conditions, linear and saturation regions, subthreshold region, mobility behavior, temperature dependence, threshold shift, short channel effects, subthreshold current, FAMOS, VMOS; types of MOSFET. Charge coupled devices (CCD); interface trapped charge, charge storage, basic CCD structure, charge storage and frequency response, buried channel CCD.

## 5. Microprocessors (9)

Introduction to microcomputers, memory-I/O interfacing devices. 8085 CPU; Architecture BUS timings, Demultiplexing the address bus generating control signals, instruction set, addressing modes, illustrative programs, writing assembly language programs: looping, counting and indexing-counters and timing delays; stack and subroutine; extension to 8086 CPU.

## 6. Nanostructures

### (a) Physics of Nanostructures (5)

Different form of nanostructures, idea of 2-d, 1-d and 0-d nanostructures; Hetrostructures - Band bending, depletion width and capacitance, inversion layer, 2-d electron gas in triangular well; subband, density of states, surface electron density; exciton, quantum size effect, electron confinement - strong and weak limit; spherical well, effects of confinement; electronic properties of Graphene and amorphous silicon; experimental techniques for nanostructure characterization.

### (b) Techniques for nanostructure fabrication (4)

Top down: UV and electron beam lithography, Ball milling; Bottom up: Atom manipulation by SPM, Dip pen nanolithography, Microcontact printing; Cluster beam evaporation, Ion beam deposition, chemical bath deposition with capping techniques, Self assembled mono layers. Synthesis of nanowires, VLS growth method, core - shell and epitaxial structures in one dimension, nanowire based devices.

## 7. Quantum transport in nanostructures (8)

Ballistic transport; Phase coherence, Aharonov - Bohm effect; density of states for 1-d system; quantized conductance, Landauer formula, conductance behavior of quantum point contact; Landauer - Buttiker formula for multileads, edge states - explanation of Quantum Hall effect; Single electron transport - Coulomb blockade, Coulomb diamond, single electron transistor (SET), molecular electronics; Kondo effect in nanostructures.

## Advanced Statistical Mechanics and its Applications

### 1. Phase transitions and critical phenomena (5+6+7)

Introduction to phase transition with examples. Critical exponents, Landau's phenomenological theory for first and second order transitions; Phase transition in Ising model in higher dimensions; Mean field theory and its validity, Gaussian model .

Scaling hypothesis, renormalisation group theory, real space renormalisation group for Ising model. Formulation of a field theory,  $\phi^4$  model, momentum shell RG.

Quantum critical phenomena

### 2. Stochastic variables and stochastic processes (10+4)

Revision of the basic ideas of probability theory; probability distribution functions; moments and cumulants; characteristic functions; the central limit theorem and the law of large numbers. Markov processes: The Chapman-Kolmogorov equation; Markov chains; Applications: (random walk, birth-death processes); the master equation; methods of solution of the master equation; efficient simulation methods for Markov processes with discrete states.

The Langevin equation and its generalisations; analytical and numerical methods of solution; Applications: (Brownian motion and the modelling of intrinsic and external noise).

### 3. **Interdisciplinary Applications (4+4+5)**

Applications in social physics: Opinion dynamics models (voter model and Sznajd model); Modeling financial systems (econophysics), concept of social force.

Complex networks: General characteristics; Prototypes (Watts-Strogatz and Barabasi-Albert models); phase transitions on and of networks.

Methods of computer simulation

## **PHY 523: Advanced III Astrophysics and Cosmology**

### **Part A: Astrophysics**

#### 1. **Measurement techniques (3)**

Distance measurements in astronomy: Various methods. Measurement of mass through different types of binary systems. Measurement of other properties such as velocity, temperature, radius, etc.

#### 2. **Spectral Classification of Stars (3)**

Saha's equation; Harvard system of classification; Absolute and apparent luminosity; Mass luminosity relation, spectroscopic parallax.

#### 3. **Evolution of Stars (13)**

Observational basis, protostars, Jeans mass, Hydrostatic equilibrium, equations of stellar structure; Scaling relations; Sources of stellar energy: gravitational collapse, fusion reactions (p-p chain, CNO cycle, triple  $\alpha$  reactions); stellar nucleosynthesis and formation of heavy elements; r- and s- processes; Evolution of low-mass and high-mass stars; White and brown dwarfs, Chandrasekhar limit; Pulsars, neutron stars

#### 4. **Galaxies (6)**

Types, structure and formation, interaction between galaxies; Active galactic nuclei and quasars.

### **Part B: Cosmology**

#### 1. **Elements of General Relativity (12)**

Curved space-time; Eötvös 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.

#### 2. **$\Lambda$ CDM Cosmology (13)**

Hubble's observation and expanding universe; Friedmann cosmology; Red shift and expansion; Big bang theory; Constituents of the universe; Dark matter and dark energy (as a nonzero cosmological constant); Early universe and decoupling; Neutrino temperature; Radiation and matter-dominated phases; Cosmic microwave background radiation, its isotropy and anisotropy properties; COBE, WMAP and Planck experiments; CMBR anisotropy as a hint to large scale structure formation; Flatness, horizon, and relic abundance problems; Inflation and the slow-roll model.

## **General Theory of Relativity**

#### 1. **The Equivalence Principle (2)**

Non-inertial frames and non-Euclidean geometry; General coordinate transformations and the general covariance of physical laws.

#### 2. **Geometrical Basis (18)**

Contravariant and covariant vectors; Tangent vectors and 1-forms; Tensors: product, contraction and quotient laws; Wedge product, closed forms; Levi-Civita symbol; Tensor densities, the invariant volume element.

Parallel transport and the affine connection; Covariant derivatives; Metric tensor, raising and lowering of indices; Christoffel connection on a Riemannian space; Geodesics; Space-time curvature; Curvature tensor; Commutator and Lie derivative; Equation for geodesic deviation; Symmetries of the curvature tensor; Bianchi identities; Isometries and Killing vectors.

### 3. **Einstein's Equations (10)**

Energy-momentum tensor and conservation laws; Einstein's equation; Hilbert's variational principle; Gravitational energy-momentum pseudotensor.

Newtonian approximation. Linearised field equations; Gravitational waves; gravitational radiation.

### 4. **Simple Solutions and Singularities (20)**

Static, spherically symmetric space-time; Schwarzschild's exterior solution; Motion of perihelion of Mercury; Bending of light; Gravitational red shift. Radar echo delay.

Black holes; Kruskal-Szekeres diagram.

Schwarzschild's interior solution; Tolman-Oppenheimer-Volkov equation; Collapse of stars; Kerr metric; Ergosphere; Reissner-Nordstrom metric; Kerr-Newman metric.

Weyl's postulate and the cosmological (Copernican) principle; Robertson-Walker metric; Anisotropies, vorticity and shear; Raychaudhuri equation; Singularity theorems of Hawking and Penrose.

## **Physics of Microwaves**

### 1. **Transmission line and waveguide (10)**

Interpretation of wave equations; Rectangular wave guide — TE and TM modes, power transmission, excitation of modes; Circular waveguide — TE, TM and TEM modes, power transmission, excitation of modes. Microstrip lines — characteristic impedance, loss and Q of microstrip lines, coplanar strip lines and shielded strip lines.

### 2. **Component (9)**

Scattering parameter and scattering matrix, properties of S-parameter; Quality factor and Q-value of a cavity resonator, Q-value of a coupled cavity; Wave guide tees, magic tee, hybrid ring, couplers; Ferrites and Faraday's rotation, gyrator, circulator, isolator and terminator;  $\lambda/4$  section filter, tuner and sliding short.

### 3. **Measurement (10)**

Smith chart, single stub and double stub matching; Microwave bridge, measurement of frequency, attenuation and phase; Measurement of dielectric parameters of amorphous solids — dielectric constant, ac conductivity, resistivity, insertion loss, return loss, shielding coefficient. Measurement of microstrip line parameters.

### 4. **Source (10)**

Conventional sources – their limitations.

(a) Vacuum tube sources — Klystron, reflex klystron, travelling wave tubes and switching tubes; Magnetrons, FWCFAs and Gyrotrons.

(b) Microwave transistors and FETs, Gunn, IMPATT, TRAPATT and parametric devices.

(c) Laser — Laser processes, Pockels-Cell; Laser modulators, infrared radiation and sources.

### 5. **Antenna (6)**

Transmitting and receiving antennas, antenna gain, resistance and bandwidth; Antenna dipoles, straight, folded and broadband dipoles; Beam width and polarisation; Antenna coupling.

### 6. **Microwave integrated circuit (5)**

Materials and fabrication technique; MOSFET fabrication, memory construction, thin film formation, planar resistor, planar inductor and planar capacitor formation; Hybrid integrated circuit formation.

## Nonlinear Dynamics

### 1. Introduction, Terminology and applicability (13)

(a) General idea of dynamical system, order of dynamical system, continuous and discrete, rheonomous and autonomous systems. (b) One-dimensional systems: Flows on the line. Fixed points and stability, graphical analysis, linear stability analysis. Existence and uniqueness of solutions. Impossibility of oscillations in one dimension, Potentials, Solving on the computer. Flows on the Circle : Possibility of oscillations, Superconducting Josephson Junction, Equivalent circuit and damped, driven pendulum analogue. (c) Bifurcations in one dimensional systems and their classifications. Imperfect bifurcations and catastrophes.

### 2. Two-Dimensional Flows (12)

(a) Linear Systems and classification. Nonlinear systems: linearization and Jacobian matrix, analysis in polar coordinates. Conservative systems, reversible systems. (b) Lyapunov function, gradient systems, Dulac criterion, limit cycle, Poincaré-Bendixson theorem, Lienard systems. Analysis of two widely separated time-scales. (c) Bifurcations in two dimensions: Hopf Bifurcation-super and sub-critical.

### 3. Chaos I (10)

One dimensional map : Stability, Liapunov exponent, chaos; Logistic map : period-doubling route to chaos, estimation of  $\lambda$  and  $\nu$  from renormalisation arguments

### 4. Chaos II (12)

Fractals : examples, similarity dimension and box dimension; Rayleigh-Benard convection : basic equations, Boussinesq approximation; Lorenz map : Stability of fixed points and appearance of strange attractors; Baker's map; Henon map : relation with periodically kicked rotator, stability of fixed points and appearance of strange attractors.

### 5. Quantum Chaos (3)

Elementary ideas of quantum chaos.

## Soft Matter Physics

### 1. Introduction (2)

Introduction to soft matter systems : liquid crystals, colloidal systems, biological membranes, macromolecules.

### 2. Liquid Crystals (20)

Structure and classification of mesophases; Molecular theories of nematic and smectic liquid crystals; Symmetry and order parameter; Landau's theory of phase transition; Generalization of Landau's theory to liquid crystals; Polymer liquid crystals.

### 3. Colloidal systems (8)

Dispersion colloids : Stability and forces, DLVO-theory, gels, emulsions and foams; Association colloids : amphiphiles, micells and critical micelle concentration in colloidal solution, lyotropic liquid crystals, biological systems.

### 4. Biological Membranes (6)

Bilayer properties; Chain rotational isomerism; Marcelja's molecular field theory to study different phases and the even-odd effect; Phase diagram.

### 5. Macromolecules (10)

Polymer : random walk polymer, self-avoiding random walk polymers, polymer solutions.

DNAs : Flory's model of DNA condensation; Polymorphism of liquid crystal states by low molecular mass double stranded DNA complexes; DNA condensation in water-polymeric solution; biological activity.

Gel Electrophoresis, Reptation Model, Gene Therapy.

### 6. Numerical methods for studying soft matter (4)

Lattice models; Coarse grain models; Gaussian overlap potential; Ellipsoidal contact potential; Computational methods.

## PHY 414, PHY 415 and PHY 424: General Experiments

1. Molecular absorption spectroscopy.
2. Atomic emission spectroscopy.
3. Acousto-optical effect using piezo-electric crystal and determination of the velocity of ultrasonic wave in liquids.
4. Interferometry with Michelson's and Jamin's interferometer.
5. Spectrophotometry — Absorption of biomolecules — study of melting.
6. Experiments with laser — its characteristics.
7. Experiments with optical fibers.
8. Study of Zeeman effect — determination of  $e/m$ , Lande  $g$ -factor of electrons.
9. Determination of  $e/m$  of electrons by magnetic focusing method.
10. Determination of Lande  $g$ -factor by ESR spectroscopy.
11. Study of para-ferromagnetic phase transition.
12. X-ray diffraction experiment — Laue spots — determination of Miller indices by gnomonic projection.
13. Calibration of audio oscillator by the method of propagation of sound wave and formation of Lissajous' figures.
14. Energy band gap of a semiconductor by four probe method.
15. Energy band gap of semiconductor by studying the luminescence spectra.
16. Verification of Bohr's atomic theory by Franck Hertz Experiment.
17. Hall coefficient of a semiconductor.
18. Dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibration.
19. Amplitude modulation and demodulation.
20. Magnetic parameters of a magnetic material by hysteresis loop tracer.
21. Filter circuits: passive and active filters (1st and 2nd order), Notch filter.
22. Design and study of multivibrators.
23. Studies on FET and MOSFET.
24. Programming with microprocessors.
25. Studies on Diac, Triac and SCR.
26. Unijunction transistors, characteristics and use as saw-tooth generator.
27. Study of plasma density and plasma temperature by glowing discharge method.
28. Study of temperature variation of refractive index of a liquid using hollow prism and laser source.
29. Study of photo-conductivity of a semiconductor material.
30. Study of Gaussian and Poisson distributions and error propagation using radioactive source and GM counter.
31. Determination of phase transition temperatures of a binary liquid crystal mixture at different concentrations.
32. Determination of persistence time in a high impedance current source.

## PHY 425: Computer Practical

### Part A

1. Plotting of functions and data; fitting etc. using gnuplot
2. Revision of numerical methods for integration, finding roots of equation, solving simultaneous linear differential equations, least squares fitting, interpolation, solving differential equations (Euler method).
3. Use of standard subroutines :
  - (i) Runge kutta method for solving differential equations (example : anharmonic oscillator)
  - (ii) Matrix diagonalisation; matrix inversion (eigenvalue problem)

### Part B

Monte Carlo methods. Applications in

1. Random number generation from different distributions: uniform, gaussian etc
2. Integration

## PHY 515 and PHY 525: Advanced Experiments

1. Debye-Scherrer, Laue and rotational X-ray photographs.
2. Study of paramagnetic salts by Guoy's balance.
3. Study of colour centers and thermoluminescence of alkali halides.
4. Study of p-n junction diode.
5. Magnetoresistance and Hall effect at elevated temperatures.
6. Dielectric constant of insulating and ferroelectric materials at room and elevated temperatures.
7. Growth of semiconducting and insulating materials and polycrystalline thin films and their characterization.
8. Optical constants of dielectric and metal films.
9. Photoconductivity and deep level transient spectroscopic studies of doped and undoped semiconducting materials.
10. Study of lifetime of minority carriers of a semiconductor.
11. Differential scanning calorimetry.
12. Study of materials by Mossbauer spectroscopy and positron annihilation technique.
13. Fabrication of Current controller for operation of diode laser.
14. Study of mode characteristics of near infrared diode laser and measurement of atmospheric oxygen absorption.
15. Measurement of optical properties of a glass plate by laser Fizeau interferometry.
16. Infrared spectra of Urea.
17.  $\alpha$  particle absorption using semiconductor detectors and multichannel analyser.
18.  $\beta$  particle absorption using GM counting system.
19.  $\beta$  spectrometry with scintillation detectors and multichannel analysers.
20.  $\gamma$  spectrometry with scintillation detectors and single-channel analysers.
21. Energy spectrum of  $\beta$  rays using  $180^\circ$  deflection type magnetic spectrometer.
22. Experiments and design with OP AMP.

23. Experiments on digital electronics.
24. Design and study of DAC/ADC.
25. Design of circuits using 555 timer.
26. Experiments on microprocessor (8085).
27. Design of astable multivibrator using transistors.
28. Study of frequency modulation.
29. Characterization of Solar cell
30. Synthesis of thin films samples by thermal evaporation method and determination of its resistance.
31. Determination of precise lattice parameter and grain size of crystalline materials by X-Ray powder diffractometer.
32. Computer Simulation of an Ising system
33. Computer Simulation of random walk

### Reference Books

#### PHY 411 : Mathematical Methods

1. G. Arfken: Mathematical Methods for Physicists
2. J. Mathews and R.L. Walker : Mathematical Methods of Physics
3. P. Dennerly and A. Krzywicki: Mathematics for Physicists
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
10. S.L. Ross: Differential Equations

#### PHY 412 : Classical and Relativistic Mechanics

1. H. Goldstein: Classical Mechanics
2. A.K. Raychaudhuri: Classical Mechanics - A Course of Lectures
3. N.C. Rana and P.S. Joag: Classical Mechanics
4. D. Strauch : Classical Mechanics
5. E.N. Moore : Theoretical Mechanics
6. A.P. French: Special Relativity

#### PHY 413 : Quantum Mechanics I

1. S. Gasiorowicz : Quantum Physics
2. P.M. Mathews and K. Venkatesan: A Text Book of Quantum Mechanics
3. E. Merzbacher: Quantum Mechanics
4. J.J. Sakurai : Modern Quantum Mechanics

#### PHY 421 : Classical Electrodynamics

1. J.D. Jackson: Classical Electrodynamics
2. W.K.H. Panofsky and M. Phillips: Classical Electricity and Magnetism
3. J.R.Reitz, F.J. Milford and R.W. Christy: Foundations of Electromagnetic theory
4. D.J. Griffiths: Introduction to Electrodynamics
5. L.D. Landau and E.M. Lifshitz: (i) Electrodynamics of Continuous Media (ii) Classical theory of fields
6. C.A. Brau, Modern Problems in Classical Electrodynamics
7. J.A. Bittencourt, Fundamentals of Plasma Physics

#### PHY 422 : Quantum Mechanics II

1. L.I. Schiff: Quantum Mechanics
2. J.J. Sakurai: Modern Quantum Mechanics
3. P.M. Mathews and K. Venkatesan: A Text Book of Quantum Mechanics
4. E. Merzbacher: Quantum Mechanics
5. Messiah: Quantum Mechanics, Vol. II
6. J.D. Bjorken and S.D. Drell: Relativistic Quantum Mechanics
7. F. Halzen and A.D. Martin: Quarks and Leptons
8. W. Greiner: Relativistic Quantum Mechanics
9. A. Lahiri and P.B. Pal: A First Book of Quantum Field Theory

PHY 423 : Electronics and Instrumentation

1. J.D. Ryder: Network, Lines and Fields
2. J. Millman and C. Halkias: Integrated Electronics
3. J.D. Ryder: Electronic Fundamental and Applications
4. J. Kennedy: Electronic Communication Systems
5. J. Millman and A. Grabel: Microelectronics
6. B.G. Streetman, S. Banerjee: Solid State Electronic Devices
7. G.F. Knoll: Radiation, Detection and Measurement
8. Sedra and Smith: Microelectronic Devices
9. Taub and Schilling: Digital Integrated Electronics
10. S.Y. Liao: Microwave Devices and Circuits
11. H.J. Reich: Microwave Principles
12. P. Bhattacharyya: Semiconductor Optoelectronic Devices
13. S.M. Sze: Physics of Semiconductor Devices
14. Boylestad and Nashelski: Electronic Devices and Circuit Theory

PHY 511 : Atomic, Molecular and Laser Physics

1. B.H. Bransden and C.J. Joachain: Physics of Atoms and Molecules
2. C. Cohen-Tannoudji, B. Dier, and F. Laloe: Quantum Mechanics vol. 1 and 2
3. R. Shankar: Principles of Quantum Mechanics
4. C.B. Banwell: Fundamentals of Molecular Spectroscopy
5. G.M. Barrow: Molecular Spectroscopy
6. K. Thyagarajan and A.K. Ghatak: Lasers, Theory and Applications
7. O. Svelto: Principles of Lasers
8. B.H. Eyring, J. Walter and G.E. Kimball: Quantum Chemistry
9. W. Demtroder: Molecular Physics
10. H. Herzberg: Spectra of Diatomic Molecules
11. J.D. Graybeal: Molecular Spectroscopy
12. M.C. Gupta: Atomic and Molecular Spectroscopy
13. B.B. Laud: Lasers and Non-linear Optics
14. A. Thorne, U. Litzen and J. Johnson: Spectrophysics

PHY 512 : Statistical Mechanics

1. F. Reif: Fundamentals of Statistical and Thermal Physics
2. R.K. Pathria: Statistical Mechanics
3. K. Huang: Statistical Mechanics
4. F. Mandl: Statistical Physics
5. H.B. Callen: Thermodynamics and an Introduction to Thermostatistics

PHY 513 : Nuclear and Particle Physics

1. J.S. Lilley, Nuclear Physics
2. M.K. Pal: Theory of Nuclear Structure
3. R.R. Roy and B.P. Nigam: Nuclear Physics
4. S.N. Ghoshal: Atomic and Nuclear Physics (Vol. 2)
5. D.H. Perkins: Introduction to High Energy Physics



6. D.J. Griffiths: Introduction to Elementary Particles
7. W.E. Burcham and M. Jobes: Nuclear and particle Physics

#### PHY 514 : Solid State Physics

1. N.W. Ashcroft and N.D. Mermin: Solid State Physics
2. J.R. Christman: Fundamentals of Solid State Physics
3. A.J. Dekker: Solid State Physics
4. C. Kittel: Introduction to Solid State Physics
5. H. Ibach and H. Luth: Solid State Physics: An Introduction to Theory and Experiment
6. J.P. Srivastava: Elements of Solid State Physics
7. J.P. McKelvey: Solid State and Semiconductor Physics

#### PHY 425 : Computer Practical

1. V. Rajaraman: Computer Programming in Fortran IV
2. V. Rajaraman: Computer Oriented Numerical Methods
3. J.M. McCulloch and M.G. Salvadori: Numerical Methods in Fortran

#### PHY 521 : Advanced I

##### Condensed Matter Physics I

1. D. Pines: Elementary Excitations in Solids
2. S. Raimes: Many Electron Theory
3. O. Madelung: Introduction to Solid State Theory
4. N.H. March and M. Parrinello: Collective Effects in Solids and Liquids
5. H. Ibach and H. Luth: Solid State Physics: An Introduction to Theory and Experiments
6. J.M. Ziman: Principles of the Theory of Solids
7. C. Kittel: Quantum Theory of Solids

##### Nuclear Structure

1. M.A. Preston and R.K. Bhaduri: Structure of the Nucleus
2. M.K.Pal: Theory of Nuclear Structure
3. W. Greiner and J.A. Maruhn: Nuclear Models
4. R.R.Roy and B.P. Nigam: Nuclear Physics
5. A. Deshalit and H. Feshbach: Theoretical Nuclear Physics Vol. I - Nuclear Structure

##### Quantum Electronics

1. Mitin, Kochelap and Stroschio: Quantum Heterostructures: Microelectronics and Optoelectronics
2. Martinez-Duart, Martin-Palma, Agullo-Rueda: Nanotechnology for Microelectronics and Optoelectronics
3. A. Yariv: Quantum Electronics
4. A.K. Ghatak and K. Thyagarajan: Optical Electronics
5. O. Svelto: Principles of Lasers
6. P. Bhattacharyya: Semiconductor Optoelectronics Devices
7. R.W. Boyd: Nonlinear Optics
8. B.G. Streetman and S. Banerjee, Solid State Electronic Devices
9. T. Suhara: Semiconductor laser fundamentals
10. S.M. Sze: Physics of Semiconductor Devices
11. J. Orton: The Story of Semiconductors
12. Rogers, Pennathur, Adams: Nanotechnology: Understanding Small Systems

##### Quantum Field Theory

1. M. Peskin and F. Schroeder: Quantum Field Theory
2. J.D. Bjorken and S.D. Drell: Relativistic Quantum Fields
3. D. Bailin and A. Love: Introduction to Gauge Field Theory
4. A. Lahiri and P.B. Pal: A First Book of Quantum Field Theory

5. F. Mandl and G. Shaw: Quantum Field Theory
6. P. Ramond: Field Theory: A Modern Primer
7. C. Itzykson and J.B. Zuber: Quantum Field Theory

### PHY 522 : Advanced II

#### Condensed Matter Physics II

1. M. Tinkham: Group Theory and Quantum Mechanics
2. M. Sachs: Solid State Theory
3. A.O.E. Animalu: Intermediate Quantum Theory of Crystalline Solids
4. N.W. Ashcroft and N.D. Mermin: Solid State Physics
5. J.M. Ziman: Principles of the Theory of Solids
6. C. Kittel: Introduction to Solid State Physics

#### Laser Physics

1. M. Sargent, M.O. Scully and W.E. Lamb: Laser Physics
2. S. Stenholm: Foundations of Laser Spectroscopy
3. P. Meystre: Atom Optics
4. H. Metcalf and P. Straten: Laser Cooling and Trapping
5. P. Meystre and M. Sargent III: Elements of Quantum Optics
6. R. Loudon: Elements of Quantum Optics

#### Materials Physics

1. C. Kittel: Introduction to Solid State Physics
2. R. Zallen: The Physics of Amorphous Solids
3. N.F. Mott and E.A. Davies: Electronic Processes in Non-crystalline Materials
4. C.N.R. Rao and B. Raveau: Colossal Magnetoresistance, Charge Density and Related Properties of Manganese oxides
5. J.M. Yeomans: Statistical Mechanics of Phase Transitions
6. R.E. Prange and S.M. Girvin (editors): The Quantum Hall Effect
7. H.P. Klug and L.E. Alexander: X-ray Diffraction Procedures

#### Nuclear Reactions and Nuclear Astrophysics

1. G.R. Satchler: Introduction to Nuclear Reactions
2. K.S. Krane: Introductory Nuclear Physics
3. R.R.Roy and B.P. Nigam: Nuclear Physics
4. J.L. Basdevant, J Rich and M. Spiro: Fundamentals in Nuclear Physics
5. C Iliadis: Nuclear Physics of Stars
6. B.E.J. Pagel: Nucleosynthesis and Chemical Evolution of Galaxies
7. G.F. Knoll: Radiation Detection Measurement

#### Particle Physics

1. F. Halzen and A.D. Martin: Quarks and Leptons
2. J. Donoghue, E. Golowich and B. Holstein: Dynamics of the Standard Model
3. T.-P. Cheng and L.-F. Li: Gauge Theories in Particle Physics
4. E. Leader and E. Predazzi: An Introduction to Gauge Theories and Modern Particle Physics
5. F.E. Close: An Introduction to Quarks and Partons

#### Solid State Electronics

1. S.M. Sze: Physics of Semiconductor Devices
2. A. Ghatak and K. Thyagarajan: Optical Electronics
3. J. Millman and A. Grabel: Microelectronics
4. R.S. Gaonkar: Microprocessor Architecture, Programming and Application with 8085/8086
5. John H. Davies: Physics of Low Dimensional Semiconductors

6. J.H. Fendler: Nanoparticles and Nanostructured Films: Preparation, Characterization and Applications
7. B.G. Streetman and S. Banerjee: Solid State Electronic Devices

#### Advanced Statistical Mechanics and its Applications

1. S. K. Ma, Modern Theory of Critical phenomena
2. H. E. Stanley, Introduction to Phase transitions and Critical Phenomena
3. J. Yeomans, Statistical Mechanics of Phase Transitions
4. S. Sachdev, Quantum Phase transitions
5. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics
6. P. L. Krapivsky, S. Redner and E. Ben-Naim, A Kinetic View of Statistical Physics
7. W. Feller, An Introduction to probability theory and its applications
8. R. N. Mantegna and H. E. Stanley, Introduction to Econophysics
9. S. Sinha, A. Chatterjee, A. Chakraborti, B. K. Chakrabarti, Econophysics: An Introduction
10. B. K. Chakrabarti, J. -I. Inoue and S. Suzuki, Quantum Ising Phases and Transitions in Transverse Ising Models
11. M. Newman, Networks: An Introduction
12. N. G. van Kampen, Stochastic processes in physics and chemistry

#### PHY 523 : Advanced III

##### Astrophysics and Cosmology

1. T. Padmanabhan: Theoretical Astrophysics, vols. 1-3
2. S. Weinberg: Gravitation and Cosmology
3. M. Rowan-Robinson: Cosmology
4. E.W. Kolb and M.S. Turner: The Early Universe
5. J.V. Narlikar: Introduction to Cosmology
6. T.T. Arny: Explorations, An Introduction to Astronomy
7. M. Zeilik and E.V.P. Smith: Introductory Astronomy and Astrophysics
8. D. Clayton: Introduction to Stellar Evolution and Nucleosynthesis
9. A. Liddle: An Introduction to Modern Cosmology
10. J.B. Hartle: Gravity
11. V. Mukhanov: Physical Foundations of Cosmology

##### General Theory of Relativity

1. J.V. Narlikar: Lectures on General Relativity and Cosmology
2. S. Weinberg: Gravitation and Cosmology
3. P.A.M. Dirac: General Theory of Relativity
4. L.D. Landau and E.M. Lifshitz: The Classical Theory of Fields
5. C.W. Misner, K.S. Thorne and J.A. Wheeler: Gravitation
6. R.M. Wald: General Theory of Relativity
7. A. Raychaudhuri, S. Banerjee and A. Banerjee: General Theory of Relativity

##### Physics of Microwaves

1. Samyel Y. Liao: Microwave Devices and Circuits
2. Herbert J. Reich: Microwave Principles
3. K.C. Gupta: Microwaves
4. M.L. Sisodia and G.S. Raghubanshi: Microwave Circuits and Passive Device
5. N. Mercuvitz: Waveguide Handbook
6. S.M. Sze: Physics of Semiconductor Devices
7. R.E. Collins: Foundations of Microwave Engineering
8. J.D. Ryder: Network Lines and Fields
9. Royal Signals: Handbook of Line Communication
10. W. Frazer; Telecommunications
11. J.D.Kraus: Antenna

### Nonlinear Dynamics

1. S. H. Strogatz, Nonlinear Dynamics and Chaos (Westview Press, Indian Edition by Levant Books, Kolkata 2007)
2. R.L. Devaney, An Introduction to Chaotic Dynamical Systems (Benjamin-Cummings, 1986, Second Edition)
3. D.W. Jordan and P. Smith, Nonlinear Ordinary Differential Equations (Oxford University Press, 2007, 4th Edition)
4. G.L. Baker and J.P. Gollub, Chaotic Dynamics - An Introduction (Cambridge University Press, 1996, Second Edition)
5. E. Ott, Chaos in Dynamical Systems (Cambridge University Press, 2002, Second Edition)
6. H.G. Schuster and W. Just, Deterministic Chaos - An Introduction (Wiley-VCH, 2005, 4th Edition)

### Soft Matter Physics

1. E.B. Priestley, P.J. Wojtowich and P. Sheng: Introduction to Liquid Crystals
2. P.G. de Gennes: Physics of Liquid Crystal
3. P.J. Collings and M. Hard: Introduction to Liquid Crystals
4. G.Cevc and D.Marsh: Phospholipid bilayers:Physical Principles and Models
5. Y.M.Yevdokimov, V.I.Salyanov, S.V.Semenov and S.G.Skuridin: DNA Liquid Crystalline Dispersions and Nanoconstructions
6. M.P.Allen and D.J.Tildesley: Computer Simulation of Liquids
7. I.W.Hamley: Introduction to Soft Matter