SYLLABUS FOR
M.Sc. COURSE IN PHYSICS

UNIVERSITY OF CALCUTTA

2022

Contents

Syllabus for the M.Sc. course in Physics

The structure of the revised syllabus for the M.Sc. course in Physics, applicable from the academic year 2022-23, is as follows.

Each paper carries 50 marks.

Semester 1	Theoretical	PHY 411	Mathematical Methods
		PHY 412	Classical and Relativistic Mechanics
		PHY 413	Quantum Mechanics I
		PHY 414	Electronics and Instrumentation
	Practical	PHY 415	General Practical 1
Semester 2	Theoretical	PHY 421	Classical Electrodynamics
		PHY 422	Quantum Mechanics II
		PHY 423	Statistical Mechanics
	Practical	PHY 424	General Practical 2
		PHY 425	Computer Practical
Semester 3	Theoretical	PHY 511	Atomic, Molecular, and Laser Physics
		PHY 512	Solid State Physics
		PHY 513	Nuclear and Particle Physics
		CBCC 1*	To be chosen by the student
		CBCC 2	To be chosen by the student
Semester 4	Theoretical	PHY 521	Advanced Paper I
		PHY 522	Advanced Paper II
		PHY 523	Advanced Paper III
	Practical	PHY 524	Advanced Experiments I
		PHY 525	Advanced Experiments II / Project†

The course has been divided into 13 theoretical and 5 experimental modules on Physics (for those who do a project for paper 525, at least 4 experimental modules), each with full marks 50. Apart from this, two 50-marks papers will be assigned for CBCS in the third semester.

The general experiments PHY 415 and PHY 424 will have a common syllabus as a pool of experiments. A similar pattern will follow for PHY 524 and PHY 525, as a pool of advanced experiments.

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

*CBCC means "Choice-based Credit Course". Two such courses are to be taken from those offered by other departments.

†Project will be offered to a limited number of students only. They will be assigned during the third semester.

Advanced I papers (PHY 521)

1. Condensed Matter Physics I
2. Nuclear Structure
3. Quantum Electronics
4. Quantum Field Theory
5. Advanced Statistical Physics and its Applications

Advanced II papers (PHY 522)

1. Condensed Matter Physics II
2. Laser Physics and Quantum Optics
3. Materials Physics
4. Nuclear Reaction and Nuclear Astrophysics
5. Particle Physics
6. Solid State Electronics

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
6. Quantum Computation and Quantum Information

Total number of lecture-hours (plus tutorials) for theoretical papers is 50 to 60 for each unit of 50 marks (core courses: PHY 411, PHY 412, PHY 413, PHY 421, PHY 422, PHY 423) and 50 for each unit of 50 marks (applied courses: rest).

The department will also offer two CBCC papers for the students of other departments. These are discussed starting from p.47 of this document.

PHY 411: Mathematical Methods

1. **Group theory (10) •**
   Definitions; Multiplication table; Rearrangement theorem; Subgroups, Cayley's theorem, Cosets, Lagrange's theorem, Conjugate classes, Invariant subgroup; Isomorphism and homomorphism; Group representations : faithful and

unfaithful representations, reducible and irreducible representations; Illustration with Z_n, S_3, S_4, A_4; Lie groups and Lie algebra with U(1), SU(2) and SO(3) as examples.

2. **Complex analysis (13) •**
   Cauchy-Riemann conditions, Cauchy's theorem, Cauchy's integral formula; Liouville's theorem; Taylor and Laurent expansion of a complex function; Analytic continuation; Classification of singularities; Branch point and branch cut; Method of steepest descent; Residue theorem and evaluation of real integrals using this theorem.

3. **Theory of second order linear homogeneous differential equations (4) •**
   Singular points, Fuchs' theorem. Linear independence of solutions — Wronskian, second solution. Sturm-Liouville theory; Hermitian operators. Gram-Schmidt orthogonalisation of linearly independent functions.

4. **Inhomogeneous differential equations: Green's functions (3) •**
   General theory in 1-D; Green's function for the Laplacian in 2-D and 3-D; Green's function for quantum mechanical scattering.

5. **Integral transforms (5) •**
   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. **Mathematical logic (4) •**
   Sentences. Binary relations on sentences: AND, OR, equivalence, implication. Truth tables of binary and higher order relations. Predicate logic. Quantifiers ("There exists" and "For all"). Rules of inference involving quantifiers.

7. **Statistics (6) •**
   Probability distribution functions; Bayes' theorem; Parameter estimation in frequentist approach — maximum likelihood and χ^2 estimation; Least square fit; Gaussian errors and their propagation.

8. **Tutorials (15) •**

Recommended reading

1. G. Arfken: Mathematical Methods for Physicists
2. J. Mathews and R.L. Walker : Mathematical Methods of Physics
3. P. Dennery 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
11. A. Zee : Group Theory in a Nutshell for Physicists.

PHY 412 : Classical and Relativistic Mechanics

1. **Lagrangian formulation (5) •**
   Some specific applications of Lagrange's equation; small oscillations, normal modes and frequencies; Noether's theorem in particle mechanics.
2. **Hamilton's principle (6) •**
   Calculus of variations; Principle of least action; Lagrange's equation from principle of least action; Legendre transformation and Hamilton's canonical equations.
3. **Canonical transformations (6) •**
   Generating functions; Canonical transformations—examples and group property; 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; Elementary properties of tensors; Inertia tensor and principal axis system; Euler's equations; Heavy symmetrical top with precession and nutation.
6. **Fluid dynamics (4) •**
   Different types of derivatives; Equation of continuity and equation of motion for an ideal fluid; Bernoulli's theorem; Concept of streamlines and vortex lines; Gravity waves and shallow waves; Non-ideal fluids and Navier-Stokes equation.
7. **Introduction to Chaos (4) •**
   Stable and unstable fixed points, Logistic map, bifurcation route to chaos.
8. **Special theory of relativity (8) •**
   Lorentz transformations; vectors and tensors in Minkowski space-time, Transformation properties, Metric tensor, Raising and lowering of indices, Contraction, Symmetric and antisymmetric tensors; 4-velocity and 4-momentum;

Covariant equations of motion; Relativistic kinematics ($1 \to 2$ decay, elastic scattering and Mandelstam variables, inelastic scattering and threshold energy); Lagrangian of a free relativistic particle.

9. **Classical fields (4) •**
   Fields as generalised coordinates; Euler-Lagrange equation for the fields from extremisation of $S = \int \mathcal{L}\, d^4x$; Conjugate momentum and Hamiltonian density; Symmetries and Noether's theorem with Schrödinger field as example.

10. **Tutorials (11) •**

Recommended reading

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. **Recapitulation of basic concepts (9) •**
   Wave packet: Gaussian wave packet; Fourier transform; Spreading of a wave packet; Fourier Transforms of δ and sine functions.
   Coordinate and Momentum space: Coordinate and Momentum representations; $\hat{x}$ and $\hat{p}$ in these representations; Parseval'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-δ potential; Application to molecular inversion; Multiple well potential, Kronig-Penney model, Aharonov-Bohm effect.

2. **Operator method in quantum mechanics (8) •**
   Formulation of quantum mechanics in vector space language; states and operators, commuting operators, commuting operators with degenerate eigenvalues, Uncertainty principle for two arbitrary operators; One dimensional harmonic oscillator by operator method. Coherent states, Landau level problem.

3. **Quantum theory of measurement and time evolution (3) •**
   Double Stern-Gerlach experiment for spin-$\frac{1}{2}$ system; Schrödinger, Heisenberg and interaction pictures. Time evolution of a two state system, spin-$\frac{1}{2}$ particle in magnetic field, Larmor's precession.

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; Two body problem in central potential: Solution of the hydrogen atom Schrödinger equation; Feynman-Hellmann theorem and applications, Kramers' relation for hydrogen atom problem.

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 (12) •**
   Time independent perturbation theory: First and second order corrections to the energy eigenvalues; First order correction to the eigenvector; Convergence of the non-degenerate perturbation theory; Degenerate perturbation theory; Application to one-electron system – Stark Effect, Fine structure calculation in hydrogen atom: Relativistic correction, Spin-orbit $L-S$ coupling; j-j coupling, Darwin term; Zeeman effect (weak and strong field limits), Hyperfine structure and the 21 cm line.
   Variational method: He atom as example; First order perturbation; Exchange degeneracy; Ritz principle for excited states for Helium atom.

7. **Test of validity of the foundations of quantum mechanics (2) •**
   The Copenhagen interpretation, the EPR paradox.

8. **Tutorials (15) •**

Recommended reading

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

PHY 414: Electronics and Instrumentation

1. **Transmission line (8) •**
   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.

2. **Electronic filters (5) •**
   Butterworth filter, low pass and high pass filters; Butterworth polynomials; RC bandpass filter; Band reject 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. **Physics of semiconductor devices I (10) •**
   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.

5. **Physics of semiconductor devices II (10) •**
   Metal semiconductor junctions- Schottky barriers; Rectifying contacts; Ohmic contacts; Typical Schottky barriers; Optoelectronic devices — LDR, Photodiodes and phototransistor, Solar cell, LED, Junction Laser; Tunnel diode, SCR, Gunn diode, TRIAC, UJT and Programmable UJT.

6. **Experimental techniques (12) •**
   Scintillation detectors; Photomultiplier Tube, Solid state detectors (Si and HPGe). Measurement of energy and time using electronic signals from the detectors and associated instrumentation, Signal processing; Multi channel analyser; Time of flight technique; Coincidence measurements true-to-chance ratio; Lock-in detection technique; Different types Internal noise, Noise calculation, Signal to noise ratio, Production and measurement of high vacuum: Rotary pump, Diffusion pump, Turbomolecular pump, Ion pump; McLeod gauge, Pirani gauge, Penning gauge.

Recommended reading

1. J.D. Ryder: Network, Lines and Fields
2. J. Millman and C. Halkias: Integrated Electronics
3. B.G. Streetman, S. Banerjee: Solid State Electronic Devices
4. G.F. Knoll: Radiation, Detection and Measurement
5. H. Taub and D. Schilling: Digital Integrated Electronics
6. P. Bhattacharyya: Semiconductor Optoelectronic Devices
7. S.M. Sze: Physics of Semiconductor Devices
8. A. D. Helfrick and W. D. Cooper: Modern Electronic Instrumentation and Measurement Techniques (Prentice Hall India)
9. J.D. Ryder: Electronic Fundamental and Applications

10. J. Kennedy: Electronic Communication Systems
11. J. Millman and A. Grabel: Microelectronics
12. A. Sedra, K. Smith, T. Carusone, V. Gaudet: Microelectronic Devices
13. S.Y. Liao: Microwave Devices and Circuits
14. H.J. Reich: Microwave Principles
15. R. Boylestad and L. Nashelski: Electronic Devices and Circuit Theory

PHY 421: Classical Electrodynamics

1. **Electrostatics and magnetostatics (10) •**
   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. **Maxwell's equations and covariant formulation (10) •**
   Maxwell's equations in co-variant form, Electromagnetic field tensor, 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 (15) •**
   Lienard-Wiechert potentials; Fields due to a charge moving with uniform velocity; Qualitative discussion of radiation from a uniformly moving charge through a medium: Cerenkov radiation (qualitative treatment only); 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. Thomson and Compton scattering.
5. **Radiation reaction (5) •**
   Radiation reaction from energy conservation; Problem with Abraham-Lorentz formula; Limitations of CED.
6. **Tutorials (15) •**

Recommended reading

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. **WKB approximation (3) •**
   Quantisation rule, tunnelling through a barrier, connection formulae, 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; Optical theorem; 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, Born series (physical interpretation)
4. **Symmetries in quantum mechanics (12) •**
   Conservation laws and degeneracy associated with symmetries; Continuous symmetries — space and time translations, rotations; Construction of representations; Rotation group, homomorphism between SO(3) and SU(2); Explicit matrix representation of generators for $j = \frac{1}{2}$ and $j = 1$; Rotation matrices; Cartesian tensors versus irreducible tensors; Irreducible spherical tensor operators, Wigner-Eckart theorem; Simple examples of Wigner-Eckart theorem; Multipole moment operator of a charge distribution; Discrete symmetries — parity and time reversal.
5. **Identical particles (3) •**
   Meaning of identity and consequences; Symmetric and antisymmetric wave-

functions; 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 γ matrices; Charge conjugation; Normalisation and completeness of spinors.

7. **Tutorials (15) •**

Recommended reading

1. L.I. Schiff: Quantum Mechanics
2. J.J. Sakurai: Modern Quantum Mechanics
3. P.M. Mathews, 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
10. B. H. Bransden and C. J. Joachain : Quantum Mechanics

PHY 423: Statistical Mechanics

1. **Introduction (5) •**
   Objectives 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 (3) •**
   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 internal energy and 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 Wall's 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 and indistinguishable particles — B-E and F-D distributions.

6. **Ideal quantum gas (8) •**
   Ideal quantum gas in microcanonical ensemble; grand partition function; statistics of occupation numbers; pressure of a quantum ideal gas. Ideal Bose gas: equation of state; Bose condensation. Ideal Fermi gas: equation of state; statistical properties. Specific heat of Bose and Fermi gases.

7. **Phase transition and critical phenomena (9) •**
   Liquid gas and magnetic phase transitions; classification of phase transitions. Critical phenomena - critical exponents, universality and scaling relations. Ising model – exact solution in one dimension by transfer matrix method; Calculation of critical exponents (alpha, beta, gamma and delta) using mean field theory (Weiss) and Landau theory; Bragg William's theory; upper critical dimension. Rudiments of real space Renormalisation Group transformations with application in Ising model in one dimension.

8. **Elementary discussions on stochastic processes (5) •**
   Probability distributions and central limit theorem; Markov processes; Random walk: derivation of the Gaussian probability distribution, Brownian motion, Langevin equation and calculation of velocity autocorrelation function; Master equation (introduction only).

9. **Non-equilibrium thermodynamics (5) •**
   Irreversible processes; Classical Linear Response Theory.

10. **Tutorials (13) •**

Recommended reading

1. M. Plischke and B. Bergersen: Equilibrium Statistical Physics.
2. J.M. Yeomans: Statistical Mechanics of Phase Transitions.
3. L.D. Landau and E.M. Lifshitz: Statistical Physics, Vol. 5 in Course in Theoretical Physics.
4. P.M. Chaikin, T.C. Lubensky: Principles of Condensed Matter Physics.
5. D. Chandler: Introduction to Modern Statistical Mechanics.
6. R.K. Pathria: Statistical Mechanics

7. K. Huang: Statistical Mechanics
8. F. Mandl: Statistical Physics
9. H.B. Callen: Thermodynamics and an Introduction to Thermostatics

PHY 511: Atomic, Molecular, and Laser Physics

1. **One-electron atoms (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 structures (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 atoms (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 (6) •**
   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, The exact solution for the rigid H_2 molecule, Coulomb, exchange and overlap integrals, 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 (5) •**
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, Analysis of IR and Raman active modes.

9. **Principles of lasers (8) •**
Elementary laser theory using rate equations, Continuous wave operation, Some laser systems: Ruby Laser, He-Ne laser, CO_2 laser, Dye laser, Higher order laser modes, Laser beam propagation, Ultrashort laser pulses (ns, ps and fs optical pulses) and Intensity modulation, Q-switching and mode locking — theory and experimental techniques.

Recommended reading

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. W. Demtroder: Molecular Physics
8. H. Herzberg: Spectra of Diatomic Molecules
9. J.D. Graybeal: Molecular Spectroscopy
10. C. J. Foot: Atomic Physics
11. R. Menzel: Photonics
12. O. Svelto: Principles of Lasers
13. B.H. Eyring, J. Walter and G.E. Kimball: Quantum Chemistry
14. W. Demtroder: Molecular Physics
15. H. Herzberg: Spectra of Diatomic Molecules
16. J.D. Graybeal: Molecular Spectroscopy

17. M.C. Gupta: Atomic and Molecular Spectroscopy
18. B.B. Laud: Lasers and Non-linear Optics
19. A. Thorne, U. Litzen and J. Johnson: Spectrophysics

PHY 512: Solid State Physics

1. **Structure of solids (7) •**
   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; Common crystal structures: NaCl and CsCl structure, Close-packed structure, Zinc blende and Wurtzite structure; Intensity of scattered X-ray, Friedel's law, Anomalous scattering; Atomic and geometric structure factors; 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; Non crystalline solids — Monatomic amorphous materials; Real space analysis, Radial distribution function, Correlation functions.
2. **Band theory of solids (9) •**
   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, FCC and BCC lattices; 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 (4) •**
   Classical and quantum theory of lattice vibration under harmonic approximation; Dispersion relations of one dimension lattices: Monatomic and diatomic cases, Concept of phonon, Characteristics of different modes, long wavelength limit; 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; Optical properties of solids, Reflectivity, Kramer-Kronig relations; Ferroelectricity, Landau theory of ferroelectric phase transition.

5. **Magnetic properties of solids (5) •**
   Origin of magnetism; Diamagnetism: quantum theory of atomic diamagnetism; Landau diamagnetism (qualitative discussion); Paramagnetism: quantum theory of paramagnetism; case of rare-earth and iron-group ions; quenching of orbital angular momentum; Van Vleck paramagnetism and Pauli paramagnetism; Ferromagnetism: Curie-Weiss law, temperature dependence of saturated magnetisation, Heisenberg's exchange interaction; 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 (4) •**
   Classification of defects; Frenkel and Schottky defects, defects by non stoichiometry; electrical conductivity of ionic crystals; Entropy calculation, Stability of defects; Classifications of dislocations; role of dislocations in plastic deformation and crystal growth; Colour centres and photoconductivity; Alloys, Hume-Rothery rules; electron compounds; Bragg-Williams theory, order-disorder transition.

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, Instability of Fermi Sea, Cooper pair; Giaver tunnelling; Flux quantisation; a.c. and d.c. Josephson effect; High-T_c superconductors (information only).

9. **Tutorials (5) •**

Recommended reading

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 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 (6) •**
   Liquid drop model, Bethe-Weizsäcker binding energy/mass formula, Fermi model, Shell model and Collective model, γ-decay.

5. **Nuclear reactions and fission (8) •**
   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.

6. **Nuclear astrophysics (5) •**
   Elementary ideas about the astrophysical reactions. Nucleosynthesis and abundance of elements. Qualitative idea of BBN, relative abundances of hydrogen, helium, and deuterium.

7. **Elementary particles and their interactions (4) •**
   Elementary particles in the SM and their interactions. Relative strengths of interactions. Typical life-time/cross-sections of processes mediated by different types of interactions. Role of Symmetries and conservation laws on the interactions of elementary particles.

8. **β-decay and weak interaction (8) •**
   Energetics of various β-decays. Fermi theory of beta decay. Fermi and Gamow Teller transitions. Parity non-conservation in beta decay. Wu's experiment.

Neutrino helicity, Goldhaber's experiment. Helicity and chirality. V-A theory, Discussion of Fermi coupling constant and qualitative introduction to the gauge theory of weak interaction.

9. **Strong interactions (6) •**
   Isospin symmetry and is application in strong interactions involving hadrons. Prediction of relative rates of reactions/decays involving hadrons of the same I-spin multiplet. Hadron classification by Iso-spin and hypercharge. Gell-Mann–Nishijima relation. Quark model and SU(3) flavour symmetry. Idea of colour.

Recommended reading

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
8. K.S. Krane: Introductory Nuclear Physics

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 ex- change, 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 sym- metry, Mermin-Wagner Theorem, 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; Anderson's pseudo-spin analysis, 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 (6) •**
   (i) Superfluid Helium-4 : Basic phenomenology; Transition and Bose-Einstein condensation; Two-fluid model; Vortices in a rotating superfluid, Roton spectrum and specific heat calculation, critical velocity. (ii) Superfluid Helium-3 : Basic phenomenology; Pair condensation in a Fermi liquid, Superfluid phases of Helium-3.

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, Scaling Theory of localisation, Critical exponents related to metal-insulator phase transition in 3d, Qualitative application of the idea to amorphous semiconductors and hopping conduction. Percolation phenomena and the associated phase transition properties.

7. **Selected topics (4) •**
   Mott transition, Stoner's criterion for metallic ferromagnet. Elementary introduction to Hubbard Model, Kondo effect.

Recommended reading

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. **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, β and γ 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. **γ-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.

Recommended reading

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. **Semiconductor laser (5)** •
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 bandgap 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 (7)** •
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; Kronig-Penney model of a super lattice—zone folding, Tight binding approximation for a super lattice. Dynamic Effects of Super lattice: Bloch oscillation and Wannier-Stark energy ladder.

3. **Quantum semiconductor laser (2)** •
Light amplification in quantum well; Quantum well laser; Strained quantum well laser.

4. **Electro-optic effect in quantum structures (2)** •
Franz-Keldysh effect in semiconductor; Quantum confined Stark effect in quantum wells.

5. **Quantum transistor (6)** •
Double barrier resonant-tunnelling structures, Resonant-tunnelling unipolar and bipolar transistor; quantum interference transistor.

6. **Nonlinear interactions of light and matter (6)** •
Nonlinear polarisation 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, Generation of Solitons, Self-phase modulation, Intensity dependent refractive index, Self-focussing, Wave equation for nonlinear optical media, Coupled wave equation for sum frequency generation, Phase matching considerations. Angle tuning.

7. **Guided wave optics (5)** •
Maxwell equations in inhomogeneous media, Radiation modes, Guided modes, Leaky modes, Quasi modes, Propagation in optical fibre, Scalar wave equation and its solution, Modes of the fibre, Modal analysis, Power carried by the multimode fibres with optimum profiles, WKB analysis of multimode fibres.

8. **Principles of maser (3) •**
Elementary theory of maser, Ammonia beam maser, Energy levels, Potential well and wave function, Methods for population inversion, Maser operation.

9. **Quantum information processing (6) •**
Quantum entanglement, Entangled states, Generation of entangled photon pairs, Principles of teleportation, Experimental demonstration of teleportation, Qubits in Quantum computation, Bloch Vector representation of qubits, Single-qubit gates, Two-qubit gates, Quantum cryptography.

10. **Quantum computation using quantum structures (8) •**
Circuit systems of quantum computation using quantum-effect devices; Quantum computation with ballistic electrons; Quantum logic gates using quantum nano structures (quantum dot / quantum wires / quantum well).

Recommended reading

1. Mitin, Kochelap and Stroscio: 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
13. Bahaa E. A. Saleh and M. C. Teich: Fundamentals of Photonics

Quantum Field Theory

1. **Canonical quantization of free fields (10) •**
Real and complex scalar fields, Dirac field, electromagnetic field, Bilinear covariants, Projection operators, Charge conjugation and parity on scalar, Dirac and electromagnetic fields.

2. **Interacting fields (6) •**
   Interaction picture, Covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagrams.

3. **QED (9) •**
   Feynman rules, Example of actual calculations: Rutherford, Bhabha, Moeller, Compton, $e^+e^- \to \mu^+\mu^-$. Decay and scattering kinematics. Mandelstam variables and use of crossing symmetry.

4. **Lorentz group (5) •**
   Continuous and discrete transformations, Group structure, Proper and improper Lorentz transformations, SL(2,C) representations, Poincare group.

5. **Higher order corrections (6) •**
   One-loop diagrams. Basic idea of regularisation and renormalisation. Degree of divergence. Calculation of self-energy of scalar in ϕ^4 theory using cut-off or dimensional regularisation.

6. **Gauge theories (14) •**
   Gauge invariance in QED, non-abelian gauge theories, QCD Lagrangian and gluon self interaction, quark-quark, quark-gluon and gluon-gluon scattering in perturbative QCD at the lowest order. Spontaneous symmetry breaking, Higgs mechanism.

Recommended reading

1. M. Peskin and F. Schroeder: Quantum Field Theory
2. A. Lahiri and P.B. Pal: A First Book of Quantum Field Theory
3. J.D. Bjorken and S.D. Drell: Relativistic Quantum Fields
4. D. Bailin and A. Love: Introduction to Gauge Field Theory
5. F. Mandl and G. Shaw: Quantum Field Theory
6. P. Ramond: Field Theory: A Modern Primer
7. A. Zee : Quantum Field Theory in a Nutshell

Advanced Statistical Mechanics and its Applications

1. **Part A: Phase transition and critical phenomena (30) •**

   (a) Short recap of phase transition and critical phenomena; Response functions and fluctuation dissipation theorem; convexity properties and shape of thermodynamic functions; critical exponents and idea of scale invariance.

(b) Mean field theory of Ising model using variational principle, critical exponents nu and eta and validity of MFT, Ising model with infinite range interaction; Landau theory (recap).

(c) Coarse graining; Kadanoff block transformation; Formulation of a field theory, Landau Ginzburg Hamiltonian (ϕ^4 model), Continuous spin Ising model; Gaussian model—critical exponents and upper critical dimension. Scaling hypothesis and scaling dimension; renormalisation group theory; real space renormalisation group with examples; momentum shell RG.

(d) Square lattice Ising model under zero external field: High and low temperature expansion, expression for critical temperature by duality transformation.

(e) Phase transitions in liquid crystals: Structure and classification of mesophases; Molecular mean field theories of nematic and smectic liquid crystals; Symmetry and order parameter; Landau's phenomenological theory of phase transitions for first and second order transitions; Metastable states; Generalization of Landau's theory to liquid crystals.

(f) Quantum critical phenomena : Introduction, Transverse Ising Model: Duality transformation and exact solution for the energy eigenvalues.

2. **Part B: Stochastic processes and nonequilibrium phenomena (25) •**

(a) Markov processes: The Chapman-Kolmogorov equation; Stationary processes and stochastic matrix, Master equation; Principle of detailed balance. Langevin equation, velocity and position correlations, probability distribution function. Dynamics of probability—Fokker-Planck and Smoluchowsky equation.

(b) Kinetic Ising model, spin flip rates in Glauber dynamics, time evolution of magnetisation in one dimension and in mean field theory. Comparison with voter model dynamics.

(c) Non-Markovian process: Polymers — Introduction, ideal chain models, radius of gyration, distribution of end-to-end vectors, free energy of ideal chain; Real chains—excluded volume and self-avoiding walks, Mayer-f function, Flory theory of polymer in good solvent and poor solvent.

(d) Nonequilibrium thermodynamics : Introduction, Conservation laws, 2nd law and entropy balance, Phenomenological equations, Onsager relations, Fluctuation dissipation theorem.

3. **Tutorials: (5) •**

Recommended reading

1. H.E. Stanley: Introduction to Phase Transitions and Critical Phenomena

2. S.K. Ma: Modern Theory of Critical phenomena
3. J. Cardy: Scaling and Renormalization in Statistical Physics
4. J. Yeomans: Statistical Physics of Phase Transitions
5. E. Ben Naim, P. Krapivsky and R. Redner: A Kinetic View of Statistical Physics
6. V. Balakrishnan: Elements of Nonequilibrium Statistical Mechanics
7. M. Rubinstein, R. H. Colby: Polymer Physics.
8. M. Doi, S.F. Edwards: The Theory of Polymer Dynamics.
9. P.-G. de Gennes: Scaling Concepts in Polymer Physics.
10. S.R. de Groot, P. Mazoor: Non-Equilibrium Thermodynamics.
11. C.W. Gardiner: Handbook of Stochastic Methods.
12. H. Risken: The Fokker-Planck Equation.
13. N.G. Van Kampen: Stochastic Processes In Physics And Chemistry.
14. S. Sachdev: Quantum Phase transitions
15. P.M. Chaikin and T.C. Lubensky: Principles of Condensed Matter Physics
16. W. Feller: An Introduction to probability theory and its applications
17. R.N. Mantegna and H.E. Stanley: Introduction to Econophysics
18. S. Sinha, A. Chatterjee, A. Chakraborti, B.K. Chakrabarti: Econophysics: An Introduction
19. B.K. Chakrabarti, J.-I. Inoue and S. Suzuki: Quantum Ising Phases and Transitions in Transverse Ising Models
20. M. Newman: Networks: An Introduction

PHY 522: Advanced II

Condensed Matter Physics II

1. **Symmetry in crystals (9) •**
   Concepts of point group; Point groups and Bravais lattices; Crystal symmetry and 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: accoustical 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.

Recommended reading

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 and Quantum Optics

1. **Atom-field interaction (5) •**
   Induced resonant transitions, The two-level atom approximation, Inclusions of decay phenomena, The time-dependent Schrödinger equation, Rotating wave approximation, The weak field case, The strong-field limit—Exact Rabi solution, Rabi flopping, Experimental observation of Rabi oscillations, Mollow-triplet.

   Density matrix: Pure case and mixed case, Rate equation for density matrix, Decay phenomena inclusion, Optical Bloch equations, Vector model of density matrix, The Bloch sphere, π-pulse.

2. **Semiclassical laser theory (6) •**
   Electromagnetic field equations, Expansion in normal modes of a cavity, Lambs self-consistency equations, Polarisation of the medium, Single mode operation, Non-linear effect in polarisation, Steady state power, Frequency pulling and pushing.

3. **Laser spectroscopy (5) •**
   Moving atom in a standing wave field, Hole burning phenomena, Lamb dip, Origin of crossover resonances in V-type three-level system, Saturation absorption spectroscopy (Theory and experiment with alkali atoms).

4. **Atomic coherence and interference (5) •**
   The Hanle effect, Coherent population trapping (CPT), Dark states, Electromagnetically induced transparency (EIT), Susceptibility under EIT condition on a lambda-type atomic system. Difference between CPT and EIT.

5. **Photon statistics and photon antibunching (8) •**
   Photon-counting statistics, Classification of light by photon statistics (Poissonian, super-Poissonian and sub-Poissonian), Coherent light: Poissonian photon statistics, super-Poissonian: Thermal light and chaotic light, sub-Poissonian light, First-order coherence and Young's double-slit experiment, First-order correlation function ($G1(r, \tau)$). Michelson stellar interferometer, Intensity interferometer, Hanbury Brown-Twiss (HB-T) interferometer, Second-order correlation function ($G2(r, \tau)$), Photon bunching and antibunching: Coherent light, Bunched light and antibunched light, HB-T laboratory setup for measuring non-classical light, Experimental demonstrations of photon antibunching, Single photon source.

6. **Coherent states and squeezed states of light (5) •**
   Phasor diagram and field quadratures, Coherent states and its significance, Coherent state in photon number representation, Distribution of coherent state: Poissonian distribution, Squeezed states, Vacuum squeezed light, Amplitude squeezed light, Phase squeezed light. Shot noise and number photon uncertainty, Laser interferometer gravitational-wave observatory (LIGO).

7. **Quantum theory of interaction of radiation field with matter (6) •**
   Quantization of electromagnetic field, Atom field interaction Hamiltonian, Dressed state, Wigner-Weisskopf theory of spontaneous emission.

8. **Laser cooling, trapping and Bose-Einstein condensation (10) •**
   Mechanical effects of light, Dynamics of an atom in a laser field, Light forces on atoms, Radiation pressure force, Dipole force, Optical potential, Doppler cooling, Optical molasses, Doppler cooling limit, Sub-Doppler cooling: Sisyphus cooling, Recoil cooling limit, Magneto-optic trap (MOT), Quadrupole trap, Bose-Einstein condensation in free space, BEC in trap potential, Experimental realisation, Evaporative cooling, Observation of condensate.

Recommended reading

1. M. Fox: Quantum Optics
2. P. Meystre and M. Sargent III: Elements of Quantum Optics
3. M. O Scully and M.S. Zubairy, Quantum Optics
4. P. Meystre: Atom Optics
5. M. Sargent, M.O. Scully and W.E. Lamb: Laser Physics

Materials Physics

1. **Physical properties of materials (6) •**
   Tensor Properties of Materials: Tensor representation of electrical and thermal conductivity, Kubo Greenwood formalism. Thermoelectric effect in crystals; Thermal expansion; Magnetic susceptibility; Magnetoresistance: Ordinary and anisotropic magneto-resistance, Giant magneto-resistance (GMR); Colossal magnetoresistance (CMR): crystal field splitting and Jahn-Teller distortion.

2. **Phase transition in materials (6) •**
   Diffusion in solids: Ficks 2nd law: Specific solutions to time dependent diffusion problems; Diffusion in substitutional alloys: Kirkendall effect; driving force, activation energies. Nucleation: Homogeneous and heterogeneous; Interface controlled vs. diffusion controlled growth, Rate laws for different growth geometries and coarsening — Avrami Equation. Spinodal decomposition: Spinodal curve, Free energy of compositional fluctuations, Kinetics of Spinodal decomposition. Ostwald ripening. Surface energy. Interfacial coherency and nanostructured materials.

3. **Nanomaterials (10) •**
   Different types of nanomaterials, Metal and semiconductor nanoparticles; Synthesis of nanomaterials: Basics; surface properties of nanomaterials, Quantum confinement: Quantum dot, Growth techniques; Variation of band gap with

crystalline size (Brus equation), Magnetic nanoparticle (MNP), Superparamagnetism, Blocking temperature. Oscillator strengths in quantum transitions and sum rules, Optical properties of quantum dot, Comparison of ideal optical absorption spectra in a bulk semiconductor (3D) and quantum dot (OD), Measurement of band gap from optical absorption spectra; Wannier-Mott excitons and Frenkel excitons, Core-Shell metallic nanoparticle, Surface plasmon resonance (SPR), Applications of nanoparticles.

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 nanotube structure, formation and characterisation; 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 modelling of materials: Hartree-Fock and density functional theory. Atomistic modelling of materials and emergent properties, Basics of DFT, Comparison with conventional wave function approach, Hohenberg-Kohn Theorem; Kohn-Sham Equation; Thomas-Fermi approximation and beyond; Atomic pseudopotentials, Basis sets: Plane waves and augmented basis sets, Plane wave based DFT calculations, Local density approximation, Generalised gradient approximation, Exchange and correlation energy in terms of density of homogeneous electron gas, Simple calculation of external potential from given density, Self-consistent calculations, Comparison of DFT surface reconstruction with STM, Remit of density functional theory and limitations. Molecular dynamics simulations for the stability of material.

6. **Experimental characterisation techniques (9) •**
   X-Ray Diffraction (XRD): XRD patterns, Intensities of reflections, Thermal effects on diffraction patterns, Identification of phases, Effects of disorder, Strain and crystallite size. Diffraction under non-ideal condition.

   Electron diffraction: Electron scattering, Interaction of electron with matter, Transmission electron microscopy (TEM), Selected area diffraction pattern, TEM Imaging: Bright field, dark field, amplitude contrast and phase contrast; Scanning electron microscopy (SEM), Energy dispersive and wavelength dispersive spectrometry.

   Neutron diffraction: Basics, nuclear and magnetic scattering, elastic neutron scattering, Diffraction patterns, Intensities of reflections, Applications: advantages and disadvantages.

Recommended reading

1. R.C.O'Handley: Modern Magnetic Materials-Principles and Applications

2. J.D. Verhoeven: Fundamentals of Physical Metallurgy
3. B.D. Cullity, S.R. Stock: Elements of X-Ray Diffraction
4. C. Suryanarayana, M. Grant Norton: X-Ray Diffraction — A Practical Approach
5. C. Barry Carter and David B. Williams: Transmission Electron Microscopy-A Textbook for Materials Science
6. G. Cao: Nanostructures and Nanomaterials — Synthesis, Properties and Applications
7. C.N. Rao, P.J.Thomas and U.G. Kulkarni: Nanocrystals: Synthesis, Properties and Applications
8. C.Delerue and M. Lanno: Nanostructures; Theory and Modeling
9. F. Giustino: Materials Modelling using Density Functional Theory
10. R.J. Martin-Palma and J.M. Martinex-Duart: Nanotechnology for microelectronics and photonics
11. C. Kittel: Introduction to Solid State Physics
12. R. Zallen: The Physics of Amorphous Solids
13. N.F. Mott and E.A. Davies: Electronic Processes in Non-crystalline Materials
14. C.N.R. Rao and B. Raveau: Colossal Magnetoresistance, Charge Density and Related Properties of Manganese oxides
15. J.M. Yeomans: Statistical Mechanics of Phase Transitions
16. R.E. Prange and S.M. Girvin (editors): The Quantum Hall Effect
17. H.P. Klug and L.E. Alexander: X-ray Diffraction Procedures

Nuclear Reaction and Nuclear Astrophysics

1. **Nuclear Reactions (21) •**

   (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 (Ek) and nuclear deformations, transfer reactions, Spectroscopic factors, Asymptotic normalisation 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 (21) •**

(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 γ-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, γ-ray detection: different detector characteristics, evaluation of level structure, lifetime measurement, polarisation measurement.

Recommended reading

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. **Review of some basic QED processes (4) •**
   Calculation of cross-section for $e^+e^- \to \mu^+\mu^-$ in c-o-m frame (with photon exchange only). Cross-section for $e^-\mu^- \to e^-\mu^-$ in a frame in which initial state μ^- is at rest.
2. **Hadron structure and QCD (12) •**
   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.
3. **Low energy weak interactions (4) •**
   Fermi theory, calculation of decay widths of π^+ and muon.
4. **Electroweak theory (10) •**
   Motivation for $SU(2)_L \times U(1)_Y$ gauge theory for electro-weak interactions. Gauge boson and fermion masses, neutral current, experimental tests. Calculation of FB asymmetry in $e^+e^- \to \mu^+\mu^-$ and decay widths of W and Z bosons (only at tree-level). Higgs boson: properties, production and detection. Reasons for looking beyond the electroweak theory.
5. **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, unitarity triangles.
6. **Neutrino physics (6) •**
   Theory of two-flavour oscillation. Neutrino mass and the PMNS matrix. Solar and atmospheric neutrino anomalies. Matter effect. Neutrino experiments.
7. **HEP experiments (3) •**
   Importance of collider experiments in development of Particle Physics. Relative merits and demerits of e^+e^- and hadronic colliders. LEP, LHC, B-factories.

Recommended reading

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

Solid State Electronics

1. **Foundation of solid state electronics (5) •**
   Boltzmann transport equation, expressions for mobility and diffusion constant in semiconductor due to velocity distribution of carriers, Einstein relation, temperature dependence of mobility, scattering of carriers by optical and acoustic phonons; magneto-transport, magneto-conductivity tensor: Hall coefficient and magneto-resistance; carrier generation, quasi Fermi level, recombination of electron hole pairs: Direct recombination, Kinetics of traps and recombination centers – Shockley Reed Hall theory; surface states, pinning of Fermi level; continuity equations, ambipolar effects; Hayens Shockley experiment and its significance.
2. **Semiconductor Technology (5) •**
   Preparation of semiconductor materials: crystal growth methods, epitaxial growth, strain for lattice mismatch, effect of strain on band structure, pseudomorphic layer; synthesis of epitaxial layer by Molecular beam epitaxy and metal organic chemical vapor deposition, growth kinetics, morphology of 2d structures; ion profile formation – diffusion and ion implantation process.
3. **JFET and MESFET (6) •**
   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 (6) •**
   Surface charge in MOS-capacitors; Capacitance and voltage characteristics of MIS structure. Family tree of MOSFETs, basic device characteristics, current-voltage relations, drain conductance and mutual conductance, temperature dependence, threshold shift, short channel effects, sub threshold current, FAMOS and VMOS.

5. **Microprocessors (10) •**
   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. **Physics of low dimension (7) •**
   Physics of Nanostructures: nanometer length scale; wide variety of nanostructures; 2-d electron gas in triangular well, exact and approximate solutions for energy eigen value and eigen functions, well width; density of states under electric field, surface electron density, many body effect; Magneto-transport in reduced dimension, Quantum Hall Effect; Interband transition in bulk semiconductor: exciton in bulk and nanostructures, spherical well, effects of confinement; single dot spectroscopy; electronic magic number, quantum size effect, unconventional symmetry in clusters; electronic properties of Graphene.

7. **Techniques for nanostructure fabrication (5) •**
   UV lithography, different printing modes, diffraction effects and limitations; electron beam lithography, Ball milling; Principles of some scanning probe microscopy, Atom manipulation by SPM, Dip pen nanolithography, Cluster beam evaporation, 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.

8. **Quantum transport in nanostructures (6) •**
   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, conductance matrix; edge states – explanation of Quantum Hall effect; Single electron transport – Coulomb blockade, Coulomb diamond, single electron transistor (SET), molecular electronics; Kondo effect in nanostructures.

Recommended reading

1. S.M. Sze: Physics of Semiconductor Devices
2. David K. Ferry: Transport in nanostructures
3. J. Millman and A. Grabel: Microelectronics
4. R.S. Gaonkar: Microprocessor Architecture, Progamming 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

PHY 523: Advanced III

Astrophysics and Cosmology

1. **Part A: Astrophysics •**

   (a) **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.

   (b) **Spectral Classification of stars (3) •**
   Saha's equation; Harvard system of classification; Absolute and apparent luminosity; Mass luminosity relation, spectroscopic parallax.

   (c) **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 α 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

   (d) **Galaxies (6) •**
   Types, structure and formation, interaction between galaxies; Active galactic nuclei and quasars.

2. **Part B: Cosmology •**

   (a) **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.

   (b) **ΛCDM 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.

Recommended reading

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

General Theory of Relativity

1. **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.

Recommended reading

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. **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, FWCFA 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.

Recommended reading

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. **Introduction (5) •**
   (a) General idea of a dynamical system, continuous and discrete, rheonomous and autonomous systems, order/dimension of dynamical system.
   (b) One-dimensional systems: Flows on the line. Fixed points and stability, graphical analysis, geometric interpretation, phase trajectory and phase portrait. 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.

2. **Bifurcations in one dimension (7) •**
   Types of bifurcations, Normal forms ,Saddle-Node, Transcritical, Pitchfork – Super and Subcritical, Hysteresis, Illustrations with some physical systems : dimensionless analysis. Imperfect bifurcations and catastrophes.

3. **Two-Dimensional Flows (10) •**
   (a) Linear Systems and classification. Phase plots. Nonlinear systems: linearization and Jacobian matrix, analysis in polar coordinates. Conservative systems, reversible systems.
   (b) Limit cycle, van der Pol oscillator, Lienard systems. Ruling out closed orbits : gradient systems, Lyapunov function, Dulac criterion. Poincare-Bendixson theorem. Weakly nonlinear oscillators, perturbative solution, solution exploiting widely separated time-scales (Two timing method).

4. **Bifurcations in two dimensions (3) •**
   Hopf Bifurcation : super and sub-critical.

5. **Chaos I (10) •**
   One dimensional map: Stability, Liapunov exponent, chaos; Logistic map : stability of fixed points and 2-cycles, period-doubling route to chaos, Renormalisation arguments.

6. **Chaos II (13) •**
   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 analysis of fixed points, two-cycles and appearance of strange attractors.

7. **Application in other fields (2) •**
   Qualitative discussion of the application of nonlinear dynamics in chemical systems. Lotka-Volterra predator-prey model.

Recommended reading

1. S. H. Strogatz, Nonlinear Dynamics and Chaos
2. R.L. Devaney, An Introduction to Chaotic Dynamical Systems
3. D.W. Jordan and P. Smith, Nonlinear Ordinary Differential Equations
4. G.L. Baker and J.P. Gollub, Chaotic Dynamics — An Introduction
5. E. Ott, Chaos in Dynamica Systems
6. H.G. Schuster and W. Just, Deterministic Chaos — An Introduction

Soft Matter Physics

1. **Introduction (2) •**

Introduction to soft matter systems : liquid crystals, colloidal systems, biological membranes, macro-molecules.

2. **Liquid Crystals (25) •**
   Structure and classification of mesophases; Phases of thermotropic and lyotropic liquid crystals.

   Molecular potential, Distribution function of phases; Maier-Saupe mean field theory of nematic crystals; Symmetry and tensor order parameter of nematic phase; Generalized mean field theory of nematic phase; Mcmillan theory of Smectic phase; Molecular potential of chiral nematic phase.

   Generalization of Landau's theory to liquid crystals, Fourth order and sixth order Landau expansion for studying N-I transition, de Gennes' extension to smectic phase, Critical fluctuation, Tricritical point.

   Computational modeling of anisotropic liquid crystal molecules, Lattice models, Coarse grained models : Gaussian overlap potential, Ellipsoidal contact potential.

   Elastic continuum theory of liquid crystals, General expression of free energy of a deformed nematic liquid crystal, Franck's elastic constants, Distortion due to external electric or magnetic field, Freederickz's transition.

3. **Colloidal systems (8) •**
   Dispersion colloids : Stability and forces, DLVO-theory, Gels, Emulsions and Foams; (basic introduction), Hydrodynamic interaction between colloidal particles, Sedimentation, Applications to biological systems.

4. **Biological Membranes (5) •**
   Bilayer properties; Chain rotational isomerism; Marcelja's molecular field theory to study different phases and the even-odd effect; Phase diagram; Membrane elasticity.

5. **Macromolecules (10) •**
   Polymer : random walk polymer, self-avoiding random walk polymers, polymer solutions.

   DNA : Flory's model of DNA condensation, DNA denaturation, Gel Electrophoresis, de Gennes' reptation model, DNA entanglement.

6. **Tutorials. (10) •**

Recommended reading

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. I.W.Hamley: Introduction to Soft Matter
6. P.M. Chaikin and T.C.Lubensky : Principles of condensed matter physics
7. J.M. Yeomans: Statistical Mechanics of Phase Transitions
8. J.K.G. Dhont: Introduction to dynamics of colloids
9. M. Kleman and O.D. Lavrentovich : Soft Matter Physics : An
10. Y.M. Yevdokimov, V.I. Salyanov, S.V. Semenov and S.G. Skuridin: DNA Liquid Crystalline Dispersions and Nanoconstructions
11. M.P. Allen and D.J. Tildesley: Computer Simulation of Liquids

Quantum Computation and Quantum Information

1. **Introduction (8) •**
   Quantum dynamics, quantum measurements and collapse hypothesis, density operators, single qubit, multiqubits, pure and mixed states, quantum gates and circuits.
2. **Quantum Correlations (12) •**
   Bell inequalities and entanglement, Schmidt decomposition, EPR paradox, quantum teleportation, theory of quantum entanglement, entanglement of pure bipartite states.
3. **Quantum Algorithm (12) •**
   Introduction to quantum algorithms. Deutsch-Jozsa algorithm, Grover's search algorithm, Simon's algorithm. Shor's factorization algorithm.
4. **Quantum Information Theory (12) •**
   Classical information theory, quantum information types and quantum channels, Shannon entropy, von Neumann entropy and its properties, no-cloning theorem
5. **Physical Realizations and Recent Developments (6) •**
   Different implementations of quantum computers, optical lattices and some recent works.

Recommended reading

1. Quantum Computation and Quantum Information, M.A. Nielsen and I.L.Chuang, Cambridge University Press 2000.
2. G. Benenti, G. Casati, G. Strini, Principles of Quantum Computation and Information. Vol. 1: Basic Concepts, Vol II: Basic Tools and Special Topics (World Scientific 2004).
3. Quantum Computing -A Gentle Introduction, E.G. Rieffel and W.H. Polak, MIT Press, 2014.

4. http://www.theory.caltech.edu/people/preskill/ph229/

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. Determination of e/m of electrons by magnetic focusing method.
9. Determination of Lande g-factor by ESR spectroscopy.
10. X-ray diffraction experiment — Laue spots — determination of Miller indices by gnomonic projection.
11. Calibration of audio oscillator by the method of propagation of sound wave and formation of Lissajous' figures.
12. Energy band gap of a semiconductor by four probe method.
13. Energy band gap of semiconductor by studying the luminescence spectra.
14. Verification of Bohr's atomic theory by Franck Hertz Experiment.
15. Hall coefficient of a semiconductor.
16. Dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibration.
17. Amplitude modulation and demodulation.
18. Magnetic parameters of a magnetic material by hysteresis loop tracer.
19. Filter circuits: passive and active filters (1st and 2nd order), Notch filter.
20. Design and study of multivibrators.
21. Studies on FET and MOSFET.
22. Studies on Diac, Triac and SCR.
23. Study of plasma density and plasma temperature by glowing discharge method.
24. Study of temperature variation of refractive index of a liquid using hollow prism and laser source.
25. Study of photo-conductivity of a semiconductor material.

26. Study of Gaussian and Poisson distributions and error propagation using radioactive source and GM counter.
27. Determination of phase transition temperatures of a binary liquid crystal mixture at different concentrations.
28. Determination of persistence time in a high impedance current source.

PHY 425: Computer Practical

Application of the following methods for numerical solutions of physical problems.

1. Random number generation;
2. Root finding through bisection and Newton-Raphson methods;
3. Numerical integration through trapezoidal and Simpson's $\frac{1}{3}$-rd methods;
4. Numerical differentiation;
5. Solution of ordinary (and coupled) differential equations through Euler's method and Runge-Kutta method;
6. Finding the eigenvalues and eigenvectors of a matrix;
7. Solution of a system of linear equations;
8. Curve fitting and interpolation;
9. Data plotting (Gnuplot/Matplotlib, 2-d and 3-d plots, histograms, plots with error bars).

`Python 2.x` or `3.x` is recommended as the programming language but `Fortran` and `C/C++` are also allowed.

Use of library packages/subroutines are encouraged.

The following problems (and minor variants) are to be attempted.

1. Solution of equation of motion, Trajectories under central force
2. Small oscillations, Damped and anharmonic oscillators
3. Projectile motion with and without air drag
4. Special relativity (e.g., decay kinematics, check of Lorentz invariance)
5. Non-linear equations, fixed points and trajectories, Lyapunov exponents etc. (e.g., in logistic map)
6. Problems from thermodynamics (e.g., calculation of work done in a cycle, specific heat)
7. Solving polynomial and transcendental equations (e.g, top motion, deuteron problem, magnetisation with Ising model and Heisenberg model, critical point)

8. Quantum mechanical problems (e.g., normalisation of wave functions, energy eigenvalues and other expectation values, perturbation theory)
9. Random walk and related problems
10. Simulating statistical distributions at different temperatures
11. Curve fitting (including linear least square fit) with given data (polynomial, power law, and exponential fits)
12. Various types of plotting

Recommended reading

1. M. Newman : Computational Physics
2. A. Kar Gupta : Scientific Computing in Python
3. W.H. Press, S.A. Teukolsky, *et al.* : Numerical Recipes
4. Tanja van Mourik : Fortran 90/95 Programming Manual
5. A. C. Marshall, J. S. Morgan and J. L. Schonfelder : Fortran 90 Course Notes
6. V. Rajaraman: Computer Oriented Numerical Methods
7. J.M. McCulloch and M.G. Salvadori: Numerical Methods in Fortran
8. R. L. Burden and J. D. Faires : Numerical Methods.

PHY 524 and PHY 525: Advanced Experiments

1. Study of Zeeman effect — determination of e/m, Lande g-factor of electrons.
2. Determination of numerical aperture, splice loss, and mode field diameter of an optical fibre.
3. Study of para-ferromagnetic phase transition.
4. Debye-Scherrer, Laue and rotational X-ray photographs.
5. Study of paramagnetic salts by Guoy's balance.
6. Study of colour centers and thermoluminiscence of alkali halides.
7. Study of p-n junction diode.
8. Magnetoresistance and Hall effect at elevated temperatures.
9. Dielectric constant of insulating and ferroelectric materials at room and elevated temperatures.
10. Growth of semiconducting and insulating materials and polycrystalline thin films and their characterization.
11. Optical constants of dielectric and metal films.

12. Photoconductivity and deep level transient spectroscopic studies of doped and undoped semiconducting materials.
13. Study of lifetime of minority carriers of a semiconductor.
14. Differential scanning calorimetry.
15. Study of materials by Mossbauer spectroscopy and positron annihilation technique.
16. Fabrication of Current controller for operation of diode laser.
17. Study of mode characteristics of near infrared diode laser and measurement of atmospheric oxygen absorption.
18. Measurement of optical properties of a glass plate by laser Fizeau interferometry.
19. Infrared spectra of Urea.
20. α particle absorption using semiconductor detectors and multichannel analyser.
21. β particle absorption using GM counting system.
22. β spectrometry with scintillation detectors and multichannel analysers.
23. γ spectrometry with scintillation detectors and single-channel analysers.
24. Energy spectrum of β rays using 180° deflection type magnetic spectrometer.
25. Unijunction transistors, characteristics and use as saw-tooth generator.
26. Experiments and design with OP AMP.
27. Experiments on digital electronics.
28. Design and study of DAC/ADC.
29. Design of circuits using 555 timer.
30. Experiments on microprocessor (8085).
31. Design of astable multivibrator using transistors.
32. Study of frequency modulation.
33. Characterization of Solar cell
34. Synthesis of thin films samples by thermal evaporation method and determination of its resistance.
35. Determination of precise lattice parameter and grain size of crystalline materials by X-Ray powder diffractometer.
36. Computer Simulation of simple systems/events in (a) Statistical Mechanics, (b) Particle and Nuclear Physics, (c) Astrophysics and Cosmology, (d) Condensed Matter and Material Physics etc.

CBCC Papers for students of other departments

CBCC-1: Physics at Different Scales I

Both CBCC-1 and CBCC-2 consist of four modules each, every module being approximately of 15 lecture-hours. Depending on the interest of students, three of these modules in each paper will be offered every year.

1. **Astrophysics •**
   Measurement of various quantities; distance, mass, temperature etc.
   Observation: HR diagram, Saha equation.
   Stellar evolution : Formation of stars, Stars in main sequence, Nuclear reaction in stars, Death of stars, white dwarfs, neutron stars, black holes.

2. **Cosmology •**
   Homogeneity and Isotropy of the Universe, Expansion of the Universe, FRW model, Hubble's Law, CMBR, Need for inflation, Dark matter and Dark energy.

3. **Statistical physics of interacting systems •**
   Basics – Phase space, ensembles etc. Calculation of partition function for simple systems, Ideal gas,
   Mean field theory for interacting particles — Van der Waals' equation.
   Phase transitions and critical phenomena, critical exponents, models.
   Weiss molecular field approximation and Bragg-Williams theory for Ising model. Validity of mean field theory, Landau theory of phase transitions. Applications.

4. **Discovery of subatomic particles – A historical perspective •**
   Discovery of the Electron: Cathode Rays, Thomson's Experiment, Measurement of electric charge.

   The Nucleus: Radioactivity, Rutherford's experiment and the discovery of the nucleus, the Neutron.

   More particles: Neutrinos, Positrons, Other antiparticles, Muons and Pions, Strange particles, Quarks.

Recommended reading

1. I. Kaplan: Nuclear Physics
2. F. Halzen and A.D. Martin: Quarks and Leptons
3. R.K. Pathria and P.D. Beale: Statistical Mechanics
4. K. Huang: Statistical Mechanics

CBCC-2: Physics at Different Scales II

1. **Physics near absolute zero •**
   The race towards absolute zero, Liquefaction of gases, Classical vs. Quantum fluids, Superfluid Helium-4 and Helium-3, Superconductivity and its applications, Bose-Einstein Condensation, Fermionic condensates.

2. **Electronic states of materials •**
   Free electrons and the Fermi energy in an arbitrary spatial dimensions, Importance of Fermi energy in electronic specific heat, Computation of Bulk modulus for non-relativistic and ultra-relativistic system; Density of States in an arbitrary dimension; Variation of low temperature specific heat with temperature in power law dispersion relation, Importance of Nanomaterials, Various processes of preparing nanomaterials, Effective Bohr radius, Variation of band gap with average crystalline size, Understanding Direct band gap and Indirect band gap from absorption spectra, Nanomagnetism, Brief introduction of qualitative features of graphene and other 2D materials, Computation of dispersion relation from tight-binding Hamiltonian, Future and perspective of 2D materials.

3. **Complex fluids •**
   Introduction to complex fluids : liquid crystals, macromolecules.

   Liquid crystals: Structure and classification of mesophases; introduction to molecular theories of liquid crystals; symmetry and order parameter.

   Macromolecules: Random walk and polymers; DNA denaturation process.

4. **Electrical conductivity •**
   Electrical conductivity and classification of materials; Metal, Semiconductor and insulator.

   Electrical conductivity of metal; classical derivation by virtue of relaxation time, the Boltzmann transport equation, Sommerfeld theory of electrical conductivity of metal.

   Electrical conductivity of semiconductors; types of semiconductors — intrinsic, p-type and n-type semiconductors, density of electronic energy states across band gap, electron and hole concentration in an intrinsic semiconductor, calculation of electrical conductivity at a finite temperature.