UNIVERSITY OF CALCUTTA

Notification No. CSR/ 75 /18

It is notified for information of all concerned that the Syndicate in its meeting held on 13.07.2018 (vide Item No.11) approved the Syllabus of Two-Year (Four-Semester) M.Sc. Course of Study in Physics under CBCS in the Post-Graduate Departments of the University and in the affiliated Colleges offering Post-Graduate Courses under this University, as laid down in the accompanying pamphlet.

The above shall be effective from the academic session 2018-2019.

Sd/- 17/08/18
(Debabrata Manna)
Deputy Registrar (Acting)

SENATE HOUSE
KOLKATA-700073
The 17th August, 2018

M.Sc. Physics

University

of

Calcutta

2018

Orientation of courses in four semesters for M.Sc in Physics

1st Semester

		Marks	Credits
PHY 411	Mathematical Methods	50	4
PHY 412	Classical and Relativistic Mechanics	50	4
PHY 413	Quantum Mechanics I	50	4
PHY 414	Electronics and Instrumentation	50	4
PHY 415	General Practical 1	50	4
		200 (Theoretical)+ 50 (Practical)=250	16 (Theoretical)+ 4 (Practical)=20

2nd Semester

		Marks	Credits
PHY 421	Classical Electrodynamics	50	4
PHY 422	Quantum Mechanics II	50	4
PHY 423	Statistical Mechanics	50	4
PHY 424	General Practical 2	50	4
PHY 425	Computer Practical	50	4
		150 (Theoretical)+ 100 (Practical)=250	12 (Theoretical)+ 8 (Practical)=20

3rd Semester

		Marks	Credits
PHY 511	Atomic, Molecular, and Laser Physics	50	4
PHY 512	Solid State Physics	50	4
PHY 513	Nuclear and Particle Physics	50	4
CBCCA	Choice Based Credit course A	50	4
CBCCB	Choice Based Credit Course B	50	4
		250 (Theoretical) =250	20 (Theoretical) =20

4th Semester

		Marks	Credits
PHY 421	Advanced Paper I	50	4
PHY 422	Advanced Paper II	50	4
PHY 423	Advanced Paper III	50	4
PHY 424	Advanced Experiments I	50	4
PHY 425	Advanced Experiments II / Project	50	4
		150 (Theoretical)+ 100 (Practical)=250	12 (Theoretical)+ 8 (Practical)=20

Total marks/credits	750 (Theoretical)+ 250(Practical)=1000	60 (Theoretical)+ 20 (Practical)=80

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

Advanced I Papers (PHY 521)

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

Advanced II Papers (PHY 522)

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

Advanced III Papers (PHY 523)

1. Astrophysics and Cosmology
2. General Theory of Relativity
3. Physics of Microwaves
4. Nonlinear Dynamics
5. Quantum Computation and Quantum Information

Detailed Syllabus for two years M.Sc Course in Physics, CU -2018

First Semester

PHY 411: Mathematical Methods $\sim$ 50 marks; 4 credits; 60 Lecture hours

Vector space and matrices
Vector space: Axiomatic definition, linear independence, bases, dimensionality, inner product; Gram-Schmidt orthogonalisation.
Matrices: Representation of linear transformations and change of base; Eigenvalues and eigenvectors; Functions of a matrix; Cayley-Hamilton theorem; Commuting matrices with degenerate eigenvalues; Orthonormality of eigenvectors. [7 lecture hours]

Group theory
Definitions; Multiplication table; Rearrangement theorem; Isomorphism and homomorphism; Illustrations with point symmetry groups; Group representations : faithful and unfaithful representations, reducible and irreducible representations; Lie groups and Lie algebra with SU(2) as an example.[10 lecture hours]

Complex analysis
Recapitulation : Complex numbers, triangular inequalities, Schwarz inequality. Function of a complex variable — single and multiple-valued function, limit and continuity; Differentiation — Cauchy-Riemann equations and their applications; Analytic and harmonic function; Complex integrals, Cauchy's theorem (elementary proof only), converse of Cauchy's theorem, Cauchy's Integral Formula and its corollaries; Series — Taylor and Laurent expansion; Classification of singularities; Branch point and branch cut; Residue theorem and evaluation of some typical real integrals using this theorem.[13 lecture hours]

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

Inhomogeneous differential equations : Green's functions [3 lecture hours]

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

Integral transforms
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. [3 lecture hours]

Tutorials [15 lecture hours]

Recommended readings
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
$\sim$ 50 marks; 4 credits; 60 Lecture hours

An overview of the Lagrangian formalism
Some specific applications of Lagarange's equation; small oscillations, normal modes and frequencies. [5 lecture hours]

Hamilton's principle
Calculus of variations; Hamilton's principle; Lagrange's equation from Hamilton's principle; Legendre transformation and Hamilton's canonical equations; Canonical equations from a variational principle; Principle of least action.[6 lecture hours]

Canonical transformations
Generating functions; examples of canonical transformations; group property; Integral variants of Poincare; Lagrange and Poisson brackets; Infinitesimal canonical transformations; Conservation theorem in Poisson bracket formalism; Jacobi's identity; Angular momentum Poisson bracket relations.[6 lecture hours]

Hamilton-Jacobi theory
The Hamilton Jacobi equation for Hamilton's principle function; The harmonic oscillator

problem; Hamilton's characteristic function; Action angle variables. [4 lecture hours]

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

Elements of Fluid Mechanics and Navier -Stokes Equation [4 lecture hours]

Introduction to Chaos
Stable and unstable fixed points, Logistic Map, bifurcation route to chaos.[4 lecture hours]

Special theory of relativity
Lorentz transformations; 4-vectors, Tensors, Transformation properties, Metric tensor, Raising and lowering of indices, Contraction, Symmetric and antisymmetric tensors; 4-dimensional velocity and acceleration; 4-momentum and 4-force; Covariant equations of motion; Relativistic kinematics (decay and elastic scattering); Lagrangian and Hamiltonian of a relativistic particle.[8 lecture hours]

Tutorials[15 lecture hours]

Recommended readings
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 $\sim$ 50 marks; 4 credits; 60 Lecture hours

Recapitulation of Basic Concepts
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; x and p in these representations; Parserval's theorem.
Eigenvalues and eigenfunctions: Momentum and parity operators; Commutativity and simultaneous eigenfunctions; Complete set of eigenfunctions; expansion of wave function in

terms of a complete set.
One-dimensional problems: Square well problem ($E > 0$); Delta-function potential; Double-δ potential; Application to molecular inversion; Multiple well potential, Kronig-Penney model, Aharonov-Bohm effect. [9 lecture hours]

Operator method in Quantum Mechanics
Formulation of Quantum Mechanics in vector space language; Uncertainty principle for two arbitrary operators; One dimensional harmonic oscillator by operator method. Coherent states, Landau level problem.[8 lecture hours]

Quantum theory of measurement and time evolution
Double Stern-Gerlach experiment for spin-$\frac{1}{2}$ system; Schrödinger, Heisenberg and interaction pictures.[3 lecture hours]

Three-dimensional problems
Three dimensional problems in Cartesian and spherical polar coordinates, 3-d well and Fermi energy; Radial equation of free particle and 3-d harmonic oscillator; Eigenvalue of a 3-d harmonic oscillator by series solution.[5 lecture hours]

Angular momentum
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 lecture hours]

Approximation Methods
Time independent perturbation theory: First and second order corrections to the energy eigenvalues; First order correction to the eigenvector; Degenerate perturbation theory; Application to one-electron system – Relativistic mass correction, Spin-orbit coupling (L-S and j-j), Zeeman effect and Stark effect.
Variational method: He atom as example; First order perturbation; Exchange degeneracy; Ritz principle for excited states for Helium atom.[14 lecture hours]

Test of validity of the Foundations of Quantum Mechanics
The Copenhagen interpretation, the EPR paradox.[2 lecture hours]

Tutorials [13 lecture hours]

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

PHY 414: Electronics and Instrumentation
∼ 50 marks; 4 credits; 60 Lecture hours

Power Circuits
Series-fed class A power amplifier; Harmonic distortion; Higher harmonic generation; Transformer coupled power amplifier; Class B power amplifier; Crossover distortion; Class AB operation, Class C operation.[5 lecture hours]

Filters
Passive filters: Propagation constant; Constant-K low pass and high pass filters; Active filters: Butterworth filter, low pass and high pass filters; Butterworth polynomials; RC bandpass filter; Bandreject Filter; Delay equalizer.[5 lecture hours]

Digital MOS circuits
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)[5 lecture hours]

Transmission line
Transmission line equation and solution; Reflection and transmission coefficient; Standing wave and standing wave ratio; Line impedance and admittance; Impedance calculation in terms of source impedance and load impedance; Smith chart.[9 lecture hours]

Physics of Semiconductor devices I
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.[8 lecture hours]

Physics of Semiconductor devices II
Metal semiconductor junctions: Schottky barriers; Rectifying contacts; Ohmic contacts; Typical Schottky barriers. Miscellaneous semiconductor devices: Tunnel diode; Photodiode; Solar cell; LED; LDR.[8 lecture hours]

Experimental Design and Error Analysis
Scintillation detectors; Solid state detectors (Si and HPGe). Measurement of energy and time using electronic signals from the detectors and associated instrumentation, Signal processing; Multi channel analyzer; Time of flight technique; Coincidence measurements true-to-chance ratio; Lock-in detection technique; Propagation of errors, Distribution, Least square fit, Criteria for goodness of fit.

Production and measurement of high vacuum: Rotary pump, Diffusion pump, Turbo-molecular pump, Ion pump; McLeod gauge, Pirani gauge, Penning gauge.[10 lecture hours]

Recommended readings

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

PHY 415: General Experiments I $\sim$ 50 marks; 4 credits

1. Molecular absorption spectroscopy.
2. Atomic emission spectroscopy.
3. Acousto-optical effect using piezo-electric crystal and determination of the velocity of ultrasonic wave in liquids.
4. Interferometry with Michelson's and Jamin's interferometer.
5. Spectrophotometry — Absorption of biomolecules — study of melting.
6. Experiments with laser — its characteristics.
7. Experiments with optical fibers.
8. Study of Zeeman effect — determination of e/m, Lande g-factor of electrons.

9. Determination of e/m of electrons by magnetic focusing method.
10. Determination of Lande g-factor by ESR spectroscopy.
11. Study of para-ferromagnetic phase transition.
12. X-ray diffraction experiment — Laue spots — determination of Miller indices by gnomonic projection.
13. Calibration of audio oscillator by the method of propagation of sound wave and formation of Lissajous' figures.
14. Energy band gap of a semiconductor by four probe method.
15. Energy band gap of semiconductor by studying the luminescence spectra.
16. Verification of Bohr's atomic theory by Franck Hertz Experiment.

Second Semester

PHY 421: Classical Electrodynamics∼ 50 marks; 4 credits; 60 Lecture hours

Electrostatics and Magnetostatics
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.[6 lecture hours]

Radiation from time-dependent sources of charges and currents
Inhomogeneous wave equations and their solutions; Radiation from localised sources and multipole expansion in the radiation zone.[5 lecture hours]

Lagrangian formulation for continuous systems and Relativistic electrodynamics
Idea of a classical field as a generalised coordinate. Euler-Lagrange equation for the field from the Lagrangian density. The field momentum and the Hamiltonian density. Poisson brackets for the fields. Equation of motion in an electromagnetic field; Electromagnetic field tensor, covariance of Maxwell's equations; Maxwell's equations as equations of motion; Lorentz transformation law for the electromagnetic fields and the fields due to a point charge in uniform motion; Field invariants; Covariance of Lorentz force equation and the equation of motion of a charged particle in an electromagnetic field; The generalised momentum; Energy-momentum tensor and the conservation laws for the electromagnetic field; Relativistic Lagrangian and Hamiltonian of a charged particle in an electromagnetic field.[13 lecture hours]

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

Radiation reaction
Radiation reaction from energy conservation; Problem with Abraham-Lorentz formula; Limitations of CED.[3 lecture hours]

Introductory Plasma Physics
Definition of plasma; Its occurrence in nature; Dilute and dense plasma; Uniform but time-

dependent magnetic field: Magnetic pumping; Static non-uniform magnetic field: MHD equations, Pinched plasma; Plasma Oscillations.[6 lecture hours]

Tutorials [15 lecture hours]

Recommended readings
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∼ 50 marks; 4 credits; 60 Lecture hours

WKB Approximation
Quantisation rule, tunnelling through a barrier, qualitative discussion of α-decay. [3 lecture hours]

Time-dependent Perturbation Theory
Time dependent perturbation theory, interaction picture; Constant and harmonic perturbations — Fermi's Golden rule; Sudden and adiabatic approximations. [6 lecture hours]

Scattering theory
Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Ramsauer-Townsend effect; Relation between sign of phase shift and attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering — Green's function in scattering theory; Lippman-Schwinger equation; Born approximation. [12 lecture hours]

Symmetries in quantum mechanics
Conservation laws and degeneracy associated with symmetries; Continuous symmetries — space and time translations, rotations; Rotation group, homomorphism between SO(3) and SU(2); Explicit matrix representation of generators for $j = \frac{1}{2}$ and $j = 1$; Rotation matrices; Irreducible spherical tensor operators, Wigner-Eckart theorem; Discrete symmetries — par-

ity and time reversal. [12 lecture hours]

Identical Particles
Meaning of identity and consequences; Symmetric and antisymmetric wavefunctions; Slater determinant; Symmetric and antisymmetric spin wavefunctions of two identical particles; Collisions of identical particles. [3 lecture hours]

Relativistic Quantum Mechanics
Klein-Gordon equation, Feynman-Stückelberg interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; Non-relativistic reduction; Helicity and chirality; Properties of γ matrices; Charge conjugation; Normalisation and completeness of spinors. [9 lecture hours]

Tutorials [15 lecture hours]

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

PHY 423: Statistical Mechanics∼ 50 marks; 4 credits; 60 Lecture hours

Introduction
Objective of statistical mechanics. Central Limit Theorem. Macrostates, microstates, phase space and ensembles. Ergodic hypothesis, postulate of equal a-priori probability and equality of ensemble average and time average. Boltzmann's postulate of entropy. Counting the number of microstates in phase space. Entropy of ideal gas : Sackur-Tetrode equation and Gibbs' paradox. Liouville's Theorem. [6 lecture hours]

Canonical Ensemble
System in contact with a heat reservoir, expression of entropy, canonical partition function, Helmholtz free energy, fluctuation of internal energy.[4 lecture hours]

Grand Canonical Ensemble
System in contact with a particle reservoir, chemical potential, grand canonical partition function and grand potential, fluctuation of particle number. Chemical potential of ideal gas. Chemical equilibrium and Saha Ionisation Equation. [3 lecture hours]

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

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

Ideal Bose and Fermi gas
Equation of state; Bose condensation; Equation of state of ideal Fermi gas; Fermi gas at finite T.[6 lecture hours]

Phase Transition and Critical Phenomeona
Ising model – partition function for one dimensional case; Chemical equilibrium and Saha ionisation formula. Phase transitions – first order and continuous, critical exponents and scaling relations. Calculation of exponents from Mean Field Theory and Landau's theory, upper critical dimension, Rudiments of Real Space Renormalisation Group Transformations.[9 lecture hours]

Non-equilibrium Statistical Mechanics
Irreversible processes, Classical Linear Response Theory, Brownian Motion, Master Equation, Fokker-Planck Equation, Fluctuation-Dissipation Theorem [8 lecture hours]

Tutorials [15 lecture hours]

Recommended readings
1. M. Plischke and B. Bergersen, Equilibrium Statistical Physics, World Scientific.
2. Statistical Mechanics of Phase Transitions, J. M. Yeomans, Clarendon Press.
3. Statistical Physics, Vol. 5 in Course in Theoretical Physics, L. D. Landau and E. M. Lifshitz, Elsevier.
4. Principles of Condensed Matter Physics, P. M. Chaikin, T. C. Lubensky, Cambridge University Press.
5. Introduction to Modern Statistical Mechanics, David Chandler, Oxford University Press.
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 424: General Experiments II ∼ 50 marks; 4 credits

1. Hall coefficient of a semiconductor.
2. Dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibration.
3. Amplitude modulation and demodulation.
4. Magnetic parameters of a magnetic material by hysteresis loop tracer.
5. Filter circuits: passive and active filters (1st and 2nd order), Notch filter.
6. Design and study of multivibrators.
7. Studies on FET and MOSFET.
8. Programming with microprocessors.
9. Studies on Diac, Triac and SCR.
10. Unijunction transistors, characteristics and use as saw-tooth generator.
11. Study of plasma density and plasma temperature by glowing discharge method.
12. Study of temperature variation of refractive index of a liquid using hollow prism and laser source.
13. Study of photo-conductivity of a semiconductor material.
14. Study of Gaussian and Poisson distributions and error propagation using radioactive source and GM counter.
15. Determination of phase transition temperatures of a binary liquid crystal mixture at different concentrations.
16. Determination of persistence time in a high impedance current source.

PHY 425: Computer Practical$\sim$ 50 marks; 4 credits;

Part A

1. Plotting of functions and data; fitting etc. using gnuplot
2. Revision of numerical methods for integration, finding roots of equation, solving simultaneous linear differential equations, least squares fitting, interpolation, solving differential equations (Euler method).
3. Use of standard subroutines :

   (i) Runge kutta method for solving differential equations (example : anharmonic oscillator)

   (ii) Matrix diagonalisation; matrix inversion (eigenvalue problem)

Part B

Monte Carlo methods. Applications in

1. Random number generation from different distributions: uniform, Gaussian etc;
2. Numerical integration.

Recommended readings

1. Tanja van Mourik : Fortran 90/95 Programming Manual
2. A. C. Marshall, J. S. Morgan and J. L. Schonfelder : Fortran 90 Course Notes
3. V. Rajaraman: Computer Oriented Numerical Methods
4. J.M. McCulloch and M.G. Salvadori: Numerical Methods in Fortran
5. R. L. Burden and J. D. Faires : Numerical Methods.

Third Semester

PHY 511: Atomic, Molecular, and Laser Physics
$\sim$ 50 marks; 4 credits; 60 Lecture hours

One Electron Atom
Introduction: Quantum States; Atomic orbital; Parity of the wave function; Angular and radial distribution functions.[2 lecture hours]

Interaction of radiation with matter
Time dependent perturbation: Sinusoidal or constant perturbation; Application of the general equations; Sinusoidal perturbation which couples two discrete states — the resonance phenomenon.
Interaction of an atom with electromagnetic wave: The interaction Hamiltonian — Selection rules; Nonresonant excitation — Comparison with the elastically bound electron model; Resonant excitation — Induced absorption and emission.[6 lecture hours]

Fine and Hyperfine structure
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.[10 lecture hours]

Many electron atom
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.[6 lecture hours]

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

Rotation and Vibration of Molecules
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. [3 lecture hours]

Spectra of Diatomic Molecules
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.[4 lecture hours]

Vibration of Polyatomic Molecules: Application of Group Theory
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.[4 lecture hours]

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

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

PHY 512 : Solid State Physics∼ 50 marks; 4 credits; 60 Lecture hours

Structure of solids

Bravais lattice, primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell; Symmetry operations and classification of 2- and 3-dimensional Bravais lattices; point group and space group (information only); Common crystal structures: NaCl and CsCl structure, close-packed structure, Zinc blende and Wurtzite structure, tetrahedral and octahedral interstitial sites, Spinel structure; Intensity of scattered X-ray, Friedel's law, Anomalous scattering; Atomic and geometric structure factors; systematic absences; Reciprocal lattice and Brillouin zone; Ewald construction; Explanation of experimental methods on the basis of Ewald construction; Electron and neutron scattering by crystals (qualitative discussion); Surface crystallography; Graphene; Real space analysis — HRTEM, STM, FIM. Non crystalline solids — Monatomic amorphous materials; Radial distribution function; Structure of vitreous silica. [9 lecture hours]

Band theory of solids

Bloch equation; Empty lattice band; Number of states in a band; Effective mass of an electron in a band: concept of holes; Classification of metal, semiconductor and insulator; Electronic band structures in solids - Nearly free electron bands; Tight binding method - application to a simple cubic lattice; Band structures in copper, GaAs and silicon; Topology of Fermi-surface; Quantization of orbits in a magnetic field, cyclotron resonance — de Haas-van Alphen effect; Boltzmann transport equation - relaxation time approximation, Sommerfeld theory of electrical conductivity. [6 lecture hours]

Lattice dynamics and Specific heat

Classical theory of lattice vibration under harmonic approximation; Dispersion relations of one dimension lattices: monatomic and diatomic cases, Characteristics of different modes, long wavelength limit, Optical properties of ionic crystal in the infrared region; Inelastic scattering of neutron by phonon; Lattice heat capacity, models of Debye and Einstein, comparison with electronic heat capacity; Anharmonic effects in crystals - thermal expansion.[6 lecture hours]

Dielectric properties of solids

Electronic, ionic, and orientational polarization; static dielectric constant of gases and solids; Complex dielectric constant and dielectric losses, relaxation time, Debye equations; Cases of distribution of relaxation time, Cole - Cole distribution parameter, Dielectric modulus; Ferroelectricity, displacive phase transition, Landau Theory of Phase Transition.[6 lecture hours]

Magnetic properties of solids

Origin of magnetism; Diamagnetism: quantum theory of atomic diamagnetism; Landau diamagnetism (qualitative discussion); Paramagnetism: classical and quantum theory of paramagnetism; case of rare-earth and iron-group ions; quenching of orbital angular momentum; Van-Vleck paramagnetism and Pauli paramagnetism; Ferromagnetism: Curie-Weiss law, temperature dependence of saturated magnetisation, Heisenberg's exchange interaction, Ferromagnetic domains - calculation of wall thickness and energy; Ferrimagnetism and antiferromagnetism. [8 lecture hours]

Magnetic resonances
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. [4 lecture hours]

Imperfections in solids
Frenkel and Schottky defects, defects by non stoichiometry; electrical conductivity of ionic crystals; classifications of dislocations; role of dislocations in plastic deformation and crystal growth; Colour centers and photoconductivity; Luminescence and phosphors; Alloys, Hume-Rothery rules; electron compounds; Bragg - Williams theory, order-disorder phenomena, superstructure lines; Extra specific heat in alloys. [5 lecture hours]

Superconductivity
Phenomenological description of superconductivity - occurrence of superconductivity, destruction of superconductivity by magnetic field, Meissner effect; Type-I and type-II superconductors; Heat capacity, energy gap and isotope effect; Outlines of the BCS theory; Giaver tunnelling; Flux quantisation; a.c. and d.c. Josephson effect; Vortex state (qualitative discussions); High T_c superconductors (information only).[6 lecture hours]

Recommended readings
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∼ 50 marks;4 credits; 60 Lecture hours

Nuclear properties
Basic nuclear properties: nuclear size, Rutherford scattering, nuclear radius and charge dis-

tribution, nuclear form factor, mass and binding energy, Angular momentum, parity and symmetry, Magnetic dipole moment and electric quadrupole moment, experimental determination, Rabi's method.[4 lecture hours]

Two-body bound state

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 lecture hours]

Two-body scattering

Experimental n-p scattering data, Partial wave analysis and phase shifts, scattering length, magnitude of scattering length and strength of scattering, Signficance of the sign of scattering length; Scattering from molecular hydrogen and determination of singlet and triplet scattering lengths, effective range theory, low energy p-p scattering, Nature of nuclear forces: charge independence, charge symmetry and isospin invariance of nuclear forces. [6 lecture hours]

Nuclear structure

Liquid drop model, Bethe-Weizsäcker binding energy/mass formula, Fermi model, Shell model and Collective model, γ-decay.[7 lecture hours]

Nuclear reactions and fission

Different types of reactions, Quantum mechanical theory, Resonance scattering and reactions — Breit-Wigner dispersion relation; Compound nucleus formation and break-up, Statistical theory of nuclear reactions and evaporation probability, Optical model; Principle of detailed balance, Transfer reactions, Nuclear fission: Experimental features, spontaneous fission, liquid drop model, barrier penetration, statistical model. Elementary ideas about astrophysical reactions, Nucleosynthesis and abundance of elements.[10 lecture hours]

β-decay and weak interaction

Energetics of various β decays, $V - A$ theory of allowed β decay, Selection rules for Fermi and Gamow-Teller transitions, Parity non-conservation and Wu's experiment, Goldhaber's experiment; Elementary ideas about the gauge theory of weak interaction. The problem of mass generation and the need for the Higgs mechanism. Pion decay. [8 lecture hours]

Strong interaction

Symmetries and conservation laws, Hadron classification by isospin and hypercharge, SU(3) algebra; Young tableaux rules for SU(3); Quarks; Colour; Gell-Mann – Okubo mass relation. Magnetic moment of hadrons. [7 lecture hours]

Electroweak theory

Elementary ideas of electroweak unification and Standard Model.[2 lecture hours]

Big bang nucleosynthesis
Qualitative idea of BBN, relative abundances of hydrogen, helium, and deuterium. [3 lecture hours]

Recommended readings
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

CBCC A: Choice Based Credit Course A $\sim$ 50 marks; 4 credits, 50 lecture hours

CBCC B: Choice Based Credit Course B $\sim$ 50 marks; 4 credits, 50 lecture hours

[DETAILS OF CBCC: ANNEXURE I , p.47]

Fourth Semester

PHY 521: Advanced I

Condensed Matter Physics I∼ 50 marks; 4 credits; 50 Lecture hours

Fundamentals of many-electron system: Hartree-Fock theory
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.[8 lecture hours]

The interacting free-electron gas: Quasi electrons and Plasmon
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.[8 lecture hours]

Spin-spin interaction: Magnons
Absence of magnetism in classical statistics; Origin of the exchange interaction; Direct exchange, super exchange, indirect exchange and itinerant exchange; Spin-waves in ferromagnets and antiferromagnets (semi classical and quantum treatment using Holstein Primakoff transformation), spontaneous symmetry breaking in magnetic systems with continuous symmetry, thermodynamics of magnons, mean field theory and critical behaviour for large S models. [8 lecture hours]

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

Superfluidity

(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 [5 lecture hours]

Disordered systems

Disorder in condensed matter — substitutional, positional and topographical disorder; Short- and long-range order; Atomic correlation function and structural descriptions of glasses and liquids; Anderson model; mobility edge; Minimum Metallic Conductivity, Qualitative application of the idea to amorphous semiconductors and hopping conduction. Percolation phenomena and the associated phase transition properties.[8 lecture hours]

Selected topics

Mott transition,Stoner's criterion for metallic ferromagnet. Elementary introduction to Hubbard Model, Kondo effect.[5 lecture hours]

‘ **Recommended readings**

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 ∼ 50 marks; 4 credits, 50 lecture hours

Nuclear Models

(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.[25 lecture hours]

Microscopic theory

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.[11 lecture hours]

γ-decay
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.[8 lecture hours]

Quark degrees of freedom
Introduction to quark degrees of freedom, Basic idea of confinement, Phenomenological Bag model, Bag model at finite temperature and equation of state.[6 lecture hours]

Recommended readings
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 $\sim$ 50 marks; 4 credits; 50 Lecture hours

Semiconductor Laser
Homojunction laser: Population inversion at a junction; Emission spectra; The basic semiconductor laser;
Heterojunction: Formation of ideal heterojunctions between (a) a p-type wide band-gap semiconductor and an n-type narrower band-gap semiconductor, (b) an n-type wide band-gap semiconductor and a p-type narrower band-gap semiconductor, (c) wide and lightly doped narrower band gap n-type semiconductors; Anderson's model of ideal heterojunction.
Heterojunction laser: Single and double heterojunction laser; Analysis of carrier confinement in a single heterojunction laser. [6 lecture hours]

Electrons in quantum structures
Energy level and wave functions for quantum well, quantum wire and quantum dot; Density

of states for quantum well, quantum wire and quantum dot; Modulation — doped quantum well; Multiple quantum well; Coupling between quantum wells.
Super lattice: The concept of a super lattice; Krönig-Penney model of a super lattice — zone folding, Tight binding approximation for a super lattice.[6 lecture hours]

Quantum Semiconductor Laser
Light amplification in quantum well; Modulation bandwidth; Strained quantum well laser; Quantum wire laser; Blue quantum well laser. [3 lecture hours]

Electro-optic effect in quantum structures
Franz-Keldysh effect in Semiconductor; Electro-optic effect in quantum wells; Electro-optic effect in super lattice.[3 lecture hours]

Parallel and Perpendicular Transport in Quantum Structures
High field electron transport — Hot electrons in quantum structures; Double barrier resonant-tunneling structures; Super lattices and ballistic injection devices.[6 lecture hours]

Quantum Transistor
Resonant-tunneling unipolar and bipolar transistor; Velocity modulation and quantum interference transistor.[6 lecture hours]

Guided wave optics
(a) Waveguide modes, Modes characteristics for a planar waveguide, Step index planar waveguide, Maxwell equations in inhomogeneous media: TE modes and TM modes, Radiation modes, Guided modes, Leaky modes, Quasi modes.
(b) Propagation in optical fibre, Numerical aperture, Pulse dispersion in fibres, Scalar wave equation and modes of the fibre, Modal analysis for a step index fibre.[5 lecture hours]

Masers
Ammonia beam maser, Energy levels, Methods for population inversion, Maser operation.[3 lecture hours]

Coherent interactions of a radiation field and an atomic system (5)
(a) Induced resonant transitions, Inclusions of decay phenomena, Rotating wave approximation, Exact Rabi Solution in the strong field, Rabi flopping, ?-pulse, Dressed state picture.
(b) Density matrix, Rate equation for density matrix, Optical Bloch equations, Vector model of density matrix, The Bloch sphere.[5 lecture hours]

Semiclassical laser theory
Electromagnetic field equations, Expansion in normal modes of a cavity, Lambs self-consistency equations, Density matrix equations, Polarization of the medium, Single mode operation, Non-linear effect in polarization, Hole burning, Steady state power, Frequency

pulling and pushing.[7 lecture hours]

Recommended readings

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 (John Wiley & Sons, Inc)

Quantum Field Theory $\sim$ 50 marks; 4 credits; 50 Lecture hours

Lorentz Group

Continuous and discrete transformations, Group structure, Proper and improper Lorentz Transformations, SL(2,C) representations, Poincare group.[5 lecture hours]

Canonical quantization of free fields

Real and complex scalar fields, Dirac field, electromagnetic field, Bilinear covariants, Projection operators, Charge conjugation and Parity on scalar, Dirac and electromagnetic fields.[9 lecture hours]

Interacting fields

Interaction picture, Covariant perturbation theory, S-matrix, Wick's theorem, Feynman diagrams. [6 lecture hours]

QED

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. [9 lecture hours]

Higher order corrections
One-loop diagrams. Basic idea of regularization and renormalization. Degree of divergence. Calculation of self-energy of scalar in ϕ^4 theory using cut-off or dimensional regularization. [6 lecture hours]

Gauge theories
Gauge invariance in QED, non-abelian gauge theories, QCD (introduction), Asymptotic freedom, Spontaneous symmetry breaking, Higgs mechanism.[10 lecture hours]

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

Advanced Statistical Mechanics and its Applications
$\sim$ 50 marks; 4 credits; 50 Lecture hours

Phase transition, critical phenomena and renormalization group
(a) Short recap of phase transitiona and critical phenomena; Landau theory; Mean field theory, Gaussian model.
(b)Scaling hypothesis, renormalisation group theory, real space renormalisation group with examples. Formulation of a field theory, ϕ^4 model, momentum shell RG.
(c) Square lattice Ising Model under zero external field: High and low temperature expansion, expression for critical temperature by duality transformation.
(d) Quantum critical phenomena : Introduction, Transverse Ising Model: Duality transformation and exact solution for the energy eigenvalues.

[18 lecture hours]

Stochastic processes and nonequilibrium phenomena

Revision of the basic ideas of probability theory; probability distribution functions; moments and cumulants; characteristic functions; the central limit theorem and the law of large numbers, large deviation theory.

Markov processes: The Chapman-Kolmogorov equation; Markov chains; master equation; Applications: random walk, birth-death processes etc.

Non-Markovian processes: Example: Self Avoiding walk: application to Polymers

Nonequilibrium phenomena: Glass transitions, Phase separation, nucleation and coarsening phenomena (domain growth).

[14 lecture hours]

Physics of Soft matters

(a) General Introduction to soft matter and basic information:

(b) Complex fluids:

(i) 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.

(ii) Biological Membranes
Bilayer properties; Chain rotational isomerism:Flory's model; Marcelja's molecular mean field theory for different phases and the even-odd effect; Phase diagram.

(iii) Macromolecules
Polymer :
DNA : Structure and biological activity; Gel Electrophoresis:de Gennes' reptation model; Flory's model of DNA condensation; Polymorphism by low molecular mass double stranded DNA complexes.

iv) Colloidal systems
Dispersion colloids : Stability and forces, DLVO-theory, gels, emulsions and foams; Association colloids : amphiphiles, micells and critical micelle concentration in colloidal solution.

(c) Numerical methods for studying Complex Fluids:

Monte carlo and Molecular dynamics simulations.

Lattice models; Coarse grained models

[18 lecture hours]

Recommended readings

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

PHY 522: Advanced II

Condensed Matter Physics II$\sim$ 50 marks; 4 credits; 50 Lecture hours

Symmetry in crystals

Concepts of point group; Point groups and Bravais lattices; Crystal symmetry space groups; Symmetry and degeneracy - crystal field splitting; Kramer's degeneracy; incommensurate structure; Quasicrystals: general idea, Fibonacci lattice, Higher dimensional space, approximate translational and rotational symmetry of two-dimensional Penrose tiling, Diffraction from Fibonacci lattice, Frank-Casper phase in metallic glass.[9 lecture hours]

Lattice dynamics

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.[10 lecture hours]

Density Functional Theory

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.[8 lecture hours]

Electronic properties: I

The Boltzmann transport equation and relaxation time; Electrical conductivity of metals, impurity scattering, ideal resistance at high and low temperatures, U-processes; Thermoelectric effects; Thermal conductivity; The Wiedemann - Franz law.[6 lecture hours]

Electronic properties: II

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.[7 lecture hours]

Optical properties of solids

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.[10 lecture hours]

Recommended readings

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 ∼ 50 marks; 4 credits, 50 lecture hours

Laser Spectroscopy
Physical Effects of Strong Fields on Atomic Matter: Basic concepts of light-induced effects on atomic matter, Inclusion of phenomenological aspects of population and depopulation in a two-level system. A stationary two-level atom in a standing wave, A moving two-level atom in traveling wave, A moving two-level atom in a standing wave, Lamb dip, Saturation phenomena, Hole burning, Physical significance, Three-level systems with two laser fields: concepts and approach.[15 lecture hours]

Quantization of the radiation field
Background and importance, Lamb shift Classical electromagnetic field, Free classical field, Quantization of electromagnetic field, Photon number states and eigenvalues, Significance of creation/annihilation operators and electric field operator. Multimode electromagnetic field. Interaction picture, Atom-field interactions (first-order perturbation theory and Rabi solution), spontaneous emission, stimulated absorption and emission, Wigner-Weiskopf theory of spontaneous emission.[10 lecture hours]

Optical fluctuations and Coherence
Coherent light: Poissonian photon statistics, Super-Poissonian light: Thermal light and chaotic light, Sub-Poissonian light. Photon antibunching: Mach-Zehnder interferometer, First-order coherence, The intensity interferometer, Hanbury-Brown Twiss experiments, Second order coherence, Photon bunching and antibunching, Coherent light, Bunched light, Antibunched light.[4 lecture hours]

Nonlinear interactions of light and matter
Nonlinear polarization of the medium, Optical susceptibility tensor, Generation of second harmonic, Sum frequency and difference frequency generation, Optical rectification, Parametric amplifier and oscillation, Generation of third harmonic, Intensity dependent refractive index, Self-focussing, Wave equation for nonlinear optical media, Coupled wave equation for sum frequency generation, Phase matching considerations.[7 lecture hours]

Mechanical effects of light
Dynamics of an atom in a laser field, Light forces on atoms, Radiation pressure force, Dipole force, Optical potential.[4 lecture hours]

Laser Cooling, Trapping and Bose-Einstein Condensation

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

Theoretical overview of Bose-Einstein Condensate, Experimental realization, Evaporative cooling, Observation of condensate. [10 lecture hours]

Recommended readings

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

Materials Physics ∼ 50 marks; 4 credits, 50 lecture hours

Physical properties of materials

Tensor Properties of Materials; Tensor representation of electrical and thermal conductivity, Onsager's principle, heat flow in crystals; Stress and Strain – effect of crystal symmetry; Thermoelectric effect in crystals; Thermal expansion; Magnetic susceptibility; The Hall effect – axial third rank tensor, relationship to symmetry, Magnetoresistance, Kubo Greenwood formalism. [6 lecture hours]

Phase transition in materials

Thermodynamics and phase diagrams: Kinetics vs. thermodynamics: Role of interface energy. Interfacial coherency and the shape of precipitates. The effect of interfacial curvature on equilibrium-Grain growth, Ostwald ripening. Surface energy and nanostructured materials. Diffusion in solids: activation energies and fast diffusion paths, Variation of diffusion constant with temperature. Ficks 2nd law: specific solutions to time dependent diffusion problems. Diffusion in substitutional alloys: Kirkendall effect; Homogeneous and heterogeneous nucleation; Interface controlled vs. diffusion controlled growth, Rate laws for different growth geometries and coarsening – Avrami Equation. Diffusionless transformations: Ordering, recrystallization, the martensite transformation (basics only). Spinodal decomposition: Spinodal curve, Free energy of compositional fluctuations, Kinetics of Spinodal decomposition. [9 lecture hours]

Magneto-resistance and its application

Ordinary and anisotropic magneto-resistance, mechanism; Giant magneto-resistance (GMR): basic properties, mechanism, Application — spin valves and spin switches; Colossal magneto-resistance (CMR): basic properties and phase diagram, comparison with GMR; structure-tolerance factor, effect of doping, charge ordering; Theoretical understanding – Double exchange mechanism, crystal field splitting and Jahn-Teller distortion, electron phonon coupling, Recent developments; Application – Magnetoresistive devices [6 lecture hours]

Exotic solids

Aperiodic solids and Quasicrystals, Fibonacci sequence, Penrose lattices and their extensions in 3 dimensions; Special carbon solids: Fullerene, Graphene and Carbon Nano Tube – Structure, formation and characterization; Synthesis; Density of States, Elementary electronic properties and band structure; Usual properties of Graphene – Dirac Fermion, single wall and multiwall carbon nanotube, Carbon nanotubule based electronic devices. [9 lecture hours]

Computational methods in Materials Physics

Quantum mechanical modeling of materials: Hartree Fock and Density Functional Theory. Atomic Pseudopotentials, Basis Sets: Plane Waves and Augmented Basis sets. Plane Wave based DFT calculations. Simplified Approaches to the electronic problem: Tight binding methods;

Atomistic modeling of materials: Many body Classical potentials, Classical force fields. Monte Carlo and Molecular dynamics simulations;

Hybrid Quamtum Mechanics Molecular Mechanics (QM-MM) method. Car-Parrinello molecular dynamics. [10 lecture hours]

Experimental characterization techniques

Structure: X-ray diffraction (XRD) patterns, Intensities of reflections, Thermal effects on diffraction patterns, Identification of phases, Effects of disorder, Strain and crystallite size;

Morphology: Scanning electron microscopy (SEM), Energy-dispersive and wavelength – dispersive spectrometry; Transmission electron microscopy (TEM), Selected area diffraction patterns, Diffraction contrast to image defects;

Defect: Positron annihilation lifetime spectroscopy, defect analysis from PAL spectroscopy, defect property correlation. [10 lecture hours]

Recommended readings

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

Nuclear Reaction and Nuclear Astrophysics
$\sim$ 50 marks; 4 credits, 50 lecture hours

Nuclear Reactions

Introduction: Survey of reactions of nuclei : 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 [2 lecture hours]

Models for nuclear reactions : 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 normalization constant (ANC).
Compound nuclear reactions : Statistical model.
R-matrix methods: Dispersion theory, One level formula. [8 lecture hours]

Heavy Ion collisions : 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. [6 lecture hours]

Nuclear Fission : Spontaneous fission, Mass energy distribution of fission fragments, Bohr-Wheeler theory, Fission isobars, Super-heavy nuclei. [4 lecture hours]

Reactions involving exotic nuclei [1 lecture hour]

Nuclear Astrophysics

Thermonuclear reactions : Reaction rates. Low energy behaviour and astrophysical S-factors, Forward and reverse reactions, Nonresonant and resonant reactions, Maxwell-Boltzmann distribution of velocities, Gamow peak. [5 lecture hours]

Big Bang nucleosynthesis : He production, Be bottleneck, Abundance of light elements. [3 lecture hours]

Stellar structure : Classical stars, Degenerate stars. [3 lecture hours]

Nuclear burning in stars : H burning, He burning, Advanced nuclear burning, Core collapse. [6 lecture hours]

Stellar nucleosynthesis : Abundance of elements, Production of nuclei, r-, s- and γ-processes. [4 lecture hours]

Experimental techniques
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, polarization measurement. [8 lecture hours]

Recommended readings
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 $\sim$ 50 marks; 4 credits, 50 lecture hours

Hadron structure and QCD
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.[15 lecture hours]

Low energy weak interactions
Fermi theory, calculation of decay widths of muon and π^+.[5 lecture hours]

Electroweak Theory
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 physics. Reasons for looking beyond the electroweak theory.[9 lecture hours]

Flavour physics
Quark mixing, absence of tree-level FCNC in the Standard Model, the CKM matrix, oscil-

lation in K and B systems, CP violation.[8 lecture hours]

Neutrino physics
Theory of two-flavour oscillation. Solar and atmospheric neutrino anomalies. Neutrino experiments. The India-based Neutrino Observatory.[6 lecture hours]

HEP experiments
Relative merits and demerits of e^+e^- and hadronic colliders, LEP, LHC, B-factories.[2 lecture hours]

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

Solid State Electronics ∼ 50 marks; 4 credits, 50 lecture hours

Foundation of Solid State Electronics

Boltzmann Transport Equation, expressions for mobility and diffusion constant, Einstein relation, temperature dependence of mobility, negative differential mobility; magnetotransport - Hall coefficient and magnetoresistance, Quantum Hall effect; recombination of electron hole pairs: Direct recombination, Kinetics of traps and recombination centers; surface states, pinning of Fermi level; continuity equations, space charge in semiconductors, relaxation effects; space charge neutrality, ambipolar effects; experimental determination of mobility, diffusion constant and lifetime of minority carriers, Hayens Shockley experiment. [8 lecture hours]

Semiconductor Technology
Preparation of semiconductor materials: different crystal growth methods, epitaxial growth, strain for lattice mismatch, effect of strain on band structure, pseudomorphic layer, heterostructures, synthesis - Molecular beam epitaxy; metal organic chemical vapor deposition; kinetics of growth; oxidation; diffusion and ion implantation process.[5 lecture hours]

JFET and MESFET
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. [5 lecture hours]

MOSFET and CCD
Surface charge in MOS-capacitors; Capacitance voltage characteristics of MIS structure; Basic device characteristics, Non-equilibrium conditions, linear and saturation regions, subthreshold region, mobility behavior, temperature dependence, threshold shift, short channel effects, subthreshold current, FAMOS, VMOS; types of MOSFET. Charge coupled devices (CCD); interface trapped charge, charge storage, basic CCD structure, charge storage and frequency response, buried channel CCD. [8 lecture hours]

Microprocessors
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. [9 lecture hours]

Nanostructures

(a) Physics of Nanostructures Different form of nanostructures, idea of 2-d, 1-d and 0-d nanostructures; Hetrostructures - Band bending, depletion width and capacitance, inversion layer, 2-d electron gas in triangular well; subband, density of states, surface electron density; exciton, quantum size effect, electron confinement - strong and weak limit; spherical well, effects of confinement; electronic properties of Graphene and amorphous silicon; experimental techniques for nanostructure characterization.[5 lecture hours]

(b) Techniques for nanostructure fabrication Top down: UV and electron beam lithography, Ball milling; Bottom up: Atom manipulation by SPM, Dip pen nanolithography, Microcontact printing; Cluster beam evaporation, Ion beam deposition, chemical bath deposition with capping techniques, Self assembled mono layers. Synthesis of nanowires, VLS growth method, core - shell and epitaxial structures in one dimension, nanowire based devices. [4 lecture hours]

Quantum transport in nanostructures
Ballistic transport; Phase coherence, Aharonov - Bohm effect; density of states for 1-d system; quantized conductance, Landauer formula, conductance behavior of quantum point contact; Landauer - Buttiker formula for multileads, edge states - explanation of Quantum Hall effect; Single electron transport - Coulomb blockade, Coulomb diamond, single electron transistor (SET), molecular electronics; Kondo effect in nanostructures.[8 lecture hours]

Recommended readings
1. S.M. Sze: Physics of Semiconductor Devices

2. A. Ghatak and K. Thyagarajan: Optical Electronics
3. J. Millman and A. Grabel: Microelectronics
4. R.S. Gaonkar: Microprocessor Architecture, 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$\sim$ 50 marks; 4 credits, 50 lecture hours

Part A: Astrophysics

Measurement techniques
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.[3 lecture hours]

Spectral Classification of Stars
Saha's equation; Harvard system of classification; Absolute and apparent luminosity; Mass luminosity relation, spectroscopic parallax.[3 lecture hours]

Evolution of Stars
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[13 lecture hours]

Galaxies
Types, structure and formation, interaction between galaxies; Active galactic nuclei and quasars.[6 lecture hours]

Part B: Cosmology

Elements of General Relativity
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.[12 lecture hours]

ΛCDM Cosmology

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.[13 lecture hours]

Recommended readings

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

General Theory of Relativity ∼ 50 marks; 4 credits, 50 lecture hours

The Equivalence Principle

Non-inertial frames and non-Euclidean geometry; General coordinate transformations and the general covariance of physical laws.[2 lecture hours]

Geometrical Basis

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; Spacetime curvature; Curvature tensor; Commutator and Lie derivative; Equation for geodesic deviation; Symmetries of the curvature tensor; Bianchi identities; Isometries and Killing vectors.[18 lecture hours]

Einstein's Equations

Energy-momentum tensor and conservation laws; Einstein's equation; Hilberts variational principle; Gravitational energy-momentum pseudotensor.
Newtonian approximation. Linearised field equations; Gravitational waves; gravitational radiation.[10 lecture hours]

Simple Solutions and Singularities
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.
Schwarzschilds 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.[20 lecture hours]

Recommended readings

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 ∼ 50 marks; 4 credits, 50 lecture hours

Transmission line and waveguide
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.[10 lecture hours]

Component
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.[9 lecture hours]

Measurement

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.[10 lecture hours]

Source

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.[10 lecture hours]

Antenna

Transmitting and receiving antennas, antenna gain, resistance and bandwidth; Antenna dipoles, straight, folded and broadband dipoles; Beam width and polarisation; Antenna coupling.[6 lecture hours]

Microwave integrated circuit

Materials and fabrication technique; MOSFET fabrication, memory construction, thin film formation, planar resistor, planar inductor and planar capacitor formation; Hybrid integrated circuit formation.[5 lecture hours]

Recommended readings

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∼ 50 marks; 4 credits; 50 Lecture hours

Introduction, Terminology and applicability
(a) General idea of dynamical system, order of dynamical system,continuous and discrete, rheonomous and autonomous systems. (b) One-dimensional systems: Flows on the line. Fixed points and stability, graphical analysis, linear stability analysis. Existence and uniqueness of solutions. Impossibility of oscillations in one dimension, Potentials, Solving on the computer. Flows on the Circle : Possibility of oscillations, Superconducting Josephson Junction, Equivalent circuit and damped, driven pendulum analogue. (c) Bifurcations in one dimensional systems and their classifications. Imperfect bifurcations and catastrophes. [13 lecture hours]

Two-Dimensional Flows
(a) Linear Systems and classification. Nonlinear systems: linearization and Jacobian matrix, analysis in polar coordinates. Conservative systems, reversible systems. (b)Lyapunov function, gradient systems, Dulac criterion, limit cycle, Poincare-Bendixson theorem, Lienard systems. Analysis of two widely separated time-scales. (c) Bifurcations in two dimensions: Hopf Bifurcation-super and sub-critical. [12 lecture hours]

Chaos I
One dimensional map : Stability, Liapunov exponent, chaos; Logistic map : period-doubling route to chaos, Renormalisation arguments.[10 lecture hours]

Chaos II
Fractals : examples, similarity dimension and box dimension; Rayleigh-Benard convection : basic equations, Boussinesq aproximation; Lorenz map : Stability of fixed points and appearence of strange attractors; Baker's map; Henon map : relation with periodically kicked rotator, stability of fixed points and appearence of strange attractors.[12 lecture hours]

Quantum Chaos
Elementary ideas of quantum chaos.[3 lecture hours]

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

Quantum Computation and Quantum Information
$\sim$ 50 marks; 4 credits; 50 Lecture hours

Introduction
Quantum dynamics, quantum measurements and collapse hypothesis, density operators, single qubit, multiqubits, pure and mixed states, quantum gates and circuits.[8 lecture hours]

Quantum Correlations
Bell inequalities and entanglement, Schmidt decomposition, EPR paradox, quantum teleportation, theory of quantum entanglement, entanglement of pure bipartite states.[12 lecture hours]

Quantum Algorithm
Introduction to quantum algorithms. Deutsch-Jozsa algorithm, Grover's search algorithm, Simon's algorithm. Shor's factorization algorithm.[12 lecture hours]

Quantum Information Theory
Classical information theory, quantum information types and quantum channels, Shannon entropy, von Neumann entropy and its properties, no-cloning theorem [12 lecture hours]

Physical Realizations and Recent Developments
Different implementations of quantum computers, optical lattices and some recent works.[6 lecture hours]

Recommended readings
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 524 : Advanced Experiments I$\sim$ 50 marks; 4 credits;

1. Debye-Scherrer, Laue and rotational X-ray photographs.
2. Study of paramagnetic salts by Guoy's balance.

3. Study of colour centers and thermoluminiscence of alkali halides.
4. Study of p-n junction diode.
5. Magnetoresistance and Hall effect at elevated temperatures.
6. Dielectric constant of insulating and ferroelectric materials at room and elevated temperatures.
7. Growth of semiconducting and insulating materials and polycrystalline thin films and their characterization.
8. Optical constants of dielectric and metal films.
9. Photoconductivity and deep level transient spectroscopic studies of doped and undoped semiconducting materials.
10. Study of lifetime of minority carriers of a semiconductor.
11. Differential scanning calorimetry.
12. Study of materials by Mossbauer spectroscopy and positron annihilation technique.
13. Fabrication of Current controller for operation of diode laser.
14. Study of mode characteristics of near infrared diode laser and measurement of atmospheric oxygen absorption.
15. Measurement of optical properties of a glass plate by laser Fizeau interferometry.
16. Infrared spectra of Urea.

PHY 525 : Advanced Experiments II$\sim$ 50 marks; 4 credits;

1. α particle absorption using semiconductor detectors and multichannel analyser.
2. β particle absorption using GM counting system.
3. β spectrometry with scintillation detectors and multichannel analysers.
4. γ spectrometry with scintillation detectors and single-channel analysers.
5. Energy spectrum of β rays using 180° deflection type magnetic spectrometer.
6. Experiments and design with OP AMP.

7. Experiments on digital electronics.
8. Design and study of DAC/ADC.
9. Design of circuits using 555 timer.
10. Experiments on microprocessor (8085).
11. Design of astable multivibrator using transistors.
12. Study of frequency modulation.
13. Characterization of Solar cell
14. Synthesis of thin films samples by thermal evaporation method and determination of its resistance.
15. Determination of precise lattice parameter and grain size of crystalline materials by X-Ray powder diffractometer.
16. 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.

Annexure I

CBCC offered by Department of Physics .

Physics at Different Scales

[This paper consists of several modules, each approximately of 15 lecture-hours. Depending on the interest of students, three of these modules 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. **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.

4. **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.

5. **Non-linear Dynamics**

   Basic concepts: General idea of dynamical system, historical developments, continuous and discrete, rheonomous and autonomous systems. One-dimensional systems: Fixed points and stability, linear stability analysis. Bifurcations in one dimensional systems and their classifications.

   Chaos: One dimensional map : Stability, Liapunov exponent, chaos, fractals.

6. **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 variational mean field theory for Ising model.
Validity of mean field theory, Landau theory of phase transitions. Applications.

7. **Discovery of Subatomic Particles – A historical perspective**

   The 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.

8. **Complex Fluids**

   Introduction: 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.

9. **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.