Department of Physics
Visva-Bharati

Syllabus for
Master of Science
programme in
Physics

2020

Foreword

The horizon of Physics and related areas is rapidly widening. It is a challenge to maintain continuity, and keep up with the developing areas of the subject. New ideas are also coming up in teaching-learning-evaluation. Visva-Bharati introduced the Choice Based Credit System (CBCS) syllabus for the B.Sc. programme which is radically different from the earlier syllabus.

All the above aspects made a radical revision of the syllabus for the M.Sc. imperative. Main features of the new syllabus are:

1. Many topics which were taught earlier in the M.Sc. have been introduced in the new B.Sc. programme.
2. The syllabus has been reduced from 1200 marks, 24 courses to 1000 marks of 20 courses. Out of the 20 courses, 15 are compulsory and 5 are elective.
3. The core of the subject has been adequately covered by the 15 Core Courses which include basic theory, experiments and computational techniques. A large number of elective courses, both theory and experiment, have been introduced which reflect recent developments of this exciting subject and diversity in the expertise of the faculty members. Students will have more flexibility in the choice of elective courses.
4. Choice of laboratory/experimental courses has been increased. Now it will be possible for a student to choose laboratory/experimental course(s) independent of his/her choice of elective theory courses.
5. Some experiments will be added in future both in the compulsory (General Laboratory) and the elective courses.

Although all universities are supposed to have implemented the CBCS syllabus, some disparity remain in terms of the teaching-learning among students coming from different universities. There will be a Bridge Course at the beginning of Semester-I to bring uniformity among the students from different universities and to recapitulate some topics. This will not be a credit course and not be reflected in the grade-card/mark sheet.

Each theory course will have 50 hours of lectures and 10 hours of tutorials. The breakup shows the expected number of lectures to cover the topic and the duration of each lecture is 1 (one) hour. The break up of the tutorials is left to the teacher concerned.

The faculty members are already using different Learning Management Systems for teaching and evaluations. These will converge to a single unified system soon.

The Dissertation and Elective Courses are designed to give the students an idea of the frontline areas in different areas of Physics. Depending upon the availability of teachers and experiments the department will try to give maximum possible choice to the students.

Implementing the new syllabus will be very demanding on the resources of the department. Success of any syllabus crucially depends on the teaching and evaluation of the students. The department shall try to live up to that challenge.

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Profile of the Department

The Department of Physics, Visva-Bharati was established in 1963 with a provision for teaching at the B.Sc. (Honours) level while the M.Sc. programme started in 1968. The alumni of the Department have made their mark in different spheres of life. They are in many prestigious positions in academic and research institutes and also in industry. Presently the Department has twenty-four (24) faculty members who have a wide range of expertise in theoretical and experimental research. There are ~200 students in the B.Sc. and M.Sc. programmes and ~50 students in the PhD programme. We have a good number of students from adjoining states including the Nort-East India and Bangladesh.

The department has been taking active role in the curricular development at both the P.G. and U.G. levels. The 'Computer Applications' courses were introduced since 1987 as the knowledge in computers and computational physics is essential ingredients of teaching-learning and research in Physics. The department has implemented the Choice Based Credit Course (CBCS) module at the U.G. level in 2017 which includes a wide choice of contemporary and advanced topics. The first batch of students studying the CBCS curriculum will graduate this year. Some modifications of the CBCS course have been done to improve the practical / hands on aspect of the course. Setting up new additional experiments for the proposed postgraduate course is high on the priority list. We have used the experience of teaching this new and conceptually novel U.G. course to formulate the new P.G. curriculum. Every year a good number of students of the department qualify various national level competitive examinations (such as NET, GATE, etc.).

During the early days, the department laid more emphasis on theoretical research due to lack of infrastructure and other constraints. In course of time, both theoretical and experimental research on wide range areas flourished with support from different funding agencies. Currently members of the faculty are engaged in research in Condensed Matter Physics, Materials Science, Nanomaterials, Electronics, Communication, Instrumentation, Quantum Optics, Laser Physics, Astrophysics, Cosmology, Mathematical Physics, Particle Physics, Nuclear Physics, etc. At present, the department receives support from a number of funding agencies, e.g., DST, DAE-BRNS, AERB, UGC, CSIR, UGC-DAE CSR (Kolkata), IUAC (New Delhi), MHRD, etc. There are several laboratories which can be used for teaching specialized topics as well as research. A list of high-end equipment available in the department is given below.

The members of the faculty use a number of experimental facilities available within the country as well as abroad to carry out their research - SINP (Kolkata), SNBCBS (Kolkata), VECC (Kolkata), Jadavpur University (Kolkata), University of Calcutta, UGC-DAE-CSR (Kolkata), Bose Institute (Kolkata), IIT-Kharagpur, NIT (Durgapur), CMERI (Durgapur), IUAC (New Delhi), DAE-CSR (Indore), IUCAA (Pune), TIFR (Mumbai), BARC (Mumbai), Microton Centre (Mangalore), NISER (Bhubaneswar), IIT (Dhanbad), NIT (Rourkela), MG University (Kottayam), NEHU (Shillong), LHC (CERN, Geneva), Osaka University (Japan), etc.

Faculty members have research collaborations, both theoretical and experimental, with institutes within India as well abroad - Max-Planck Institute for Astrophysics (Garching, Germany), Naresuan University (Thailand), Fukushima University (Japan), Osaka University (Japan), University of La Plata (Argentina), International Islamic University of Malaysia (Malaysia), Nicolaus Copernicus University (Poland), University of Silesia (Poland), National University of Uzbekistan (Tashkent, Uzbekistan), University of Yogyakarta (Indonesia), Virginia Commonwealth University (USA), Gerhard Mercator University (Germany), University of Koeln (Germany), etc.

The department is an associate centre of the Theoretical Physics Seminar Circuit (TPSC). The department regularly organizes seminars, conferences and workshops on current topics at the National and International Level. The seminars allow the students as well as the faculty members to interact the latest developments Popularization of physics among school students and other outreach programmes are also carried out regularly.

List of Major Equipment Available in the Department

1. TG-DSC Set-up (Netzsch, Germany) – a DST-FIST Facility
2. Dielectric Property Measuring Set-up (100 – 5 MHz, 30-400 deg, Hioki, Japan)
3. Electrical Conductivity Measuring Set-up (~pA, ~1000V, 0 – 100 deg-C, Keithley)
4. DSP based gamma-spectrometer systems (CAEN & CANBERRA) – 2 nos
5. VME-based data acquisition system for Si-strip detectors (Mesytec)
6. X-Ray powder Diffractometer (D/Max Ultima IV Automatic high resolution type, Rigaku, Japan) – a DST-FIST Facility
7. I-V/C-V spectrum analyzer (Keithley, 4200 SCS)
8. External cavity diode laser spectrometer (852 nm, mode hop free tuning range 10 GHz).
9. External cavity diode laser spectrometer (890nm - 920 nm, mode hop free tuning range 10 GHz @ 920 nm)
10. Digital storage oscilloscope (200 MHz)
11. Power meter
12. Cesium vapour cells with and without buffer gas
13. Constant temperature heater
14. High End Computing Facility – a DST-FIST Facility
15. DSC (Model 200 F3 MAIA, Netzsch, Germany)
16. Portable Raman Spectrometer (R3000 – 785 NM)
17. Fast -Fast coincidence system for PLS with XP2020Q
18. High Temperature Annealing Furnace with Turbo Molecular Pump.

Programme Objectives

The Masters programme in any subject is essentially a human resource development programme and has to take into consideration the societal requirement. While a good number of the students who completes the course will pursue careers in academics, for many this will be the last course in Physics after which they will seek employment in diverse areas from teaching to administration, industry and business. The course should equip both these groups adequately.

This M.Sc. syllabus aims to maintain a fine balance between teaching the fundamental topics in detail as well as introducing the more curious minds to the emerging areas of the subject. The structure of the syllabus and the available elective topics reflect this effort. Adequate coverage is provided for the core topics - Classical Mechanics, Quantum Mechanics, Mathematical Physics, Statistical Physics, Electromagnetic Theory, Field theory, Solid State Physics, Electronics, Atomic and Molecular Physics and Nuclear and Particle Physics. The student should also learn to use advanced experimental and computational tools. There is a wide range of elective papers which include interdisciplinary topics. This should ensure that a student can quickly grasp any new topic he or she confronts during his research or professional career. The dissertation should give the student a preview of research. Thus the M.Sc. course is to lay the solid foundation for research in Physics as well as interdisciplinary areas. Also, the students will be able to use their knowledge and analytical and problem solving skills in other spheres of life – teaching, industry, business, etc.

Structure of the M.Sc. (Physics) Course

	Course	Type	Code
Semester I			
	Bridge Course (Theory, Computer)		
1	Classical Mechanics	Core/Theory	MPCC11
2	Classical Electrodynamics	Core/Theory	MPCC12
3	Mathematical Methods in Physics	Core/Theory	MPCC13
4	Quantum Mechanics I	Core/Theory	MPCC14
5	General Laboratory I	Core/Experiment	MPCC15
Semester II			
6	Quantum Mechanics II	Core/Theory	MPCC21
7	Statistical Mechanics	Core/Theory	MPCC22
8	Solid State Physics	Core/Theory	MPCC23
9	Electronics	Core/Theory	MPCC24
10	Computational and Numerical Methods in Physics	Core/Computation	MPCC25
Semester III			
11	Atomic and Molecular Physics	Core/Theory	MPCC31
12	Nuclear & Particle Physics	Core/Theory	MPCC32
13	Relativistic Mechanics & Field Theory	Core/Theory	MPCC33
14	General Laboratory II	Core/Experiment	MPCC34
15	Elective Course I	Elective	MPEC35
Semester IV			
16	General Laboratory III	Core/Experiment	MPCC41
17	Elective Course II	Elective	MPEC42
18	Elective Course III	Elective	MPEC43
19	Elective Courses IV	Elective	MPEC44
20	Dissertation	Elective	MPDC45

Total Courses – 20 : Compulsory Courses – 15, Choice Based Courses – 5 (Dissertation + Elective – 4). Each course is equivalent to 4 credits corresponding to 50 marks.

Classical Mechanics – MPCC11

Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Lagrangian Formalism : Lagrangian formalism in different systems, Hamilton's canonical equation and their applications, Principle of least action, Equivalent and inequivalent Lagrangian. **8 Lectures**

Canonical Transformations : Canonical transformations, examples of canonical transformations, Lagrange and Poisson bracket and their applications, invariance of Poisson bracket, infinitesimal canonical transformation, generators for infinitesimal symmetry transformation, Noether's theorem, integral invariance of Poincare, conservation theorems and angular momentum relation in Poisson bracket, Liouville theorem. **8 Lectures**

Hamilton-Jacobi Equation : Hamilton-Jacobi equation and characteristics functions, physical significance of this function, application of Hamilton-Jacobi equation, action and angle variables, importance of action angle variable, semi-classical approach to quantum mechanics from classical mechanics, time dependent and time independent perturbation theory and its application, adiabatic invariant. **12 Lectures**

Rigid Bodies : Independent coordinates, orthogonal transformations and rotations (finite and infinitesimal), Euler theorem, Euler angle, inertia tensor and principal axes system, Euler equations, heavy symmetrical top. **8 Lectures**

Theory of Small Oscillations: General case of coupled oscillations, eigen modes and eigen frequencies, normal coordinates **4 Lectures**

Dynamical System : Phase space and phase portrait, first order and second order systems, prey-predator competing species system and war, Limit cycles, system of higher order, Sensitivity to initial condition and predictability, Introduction to chaos, stable and unstable fixed point, logistic map, bifurcation route to chaos. **10 Lectures**

Suggested References:

1. Classical Mechanics – H. Goldstein, Addison Wesley
2. Mechanics – L.D. Landau and E.M. Lifshitz, Pearson New International Edition
3. Classical Mechanics – N.C. Rana and P.S. Joag, Tata McGraw-Hill
4. Classical Dynamics – S.T. Thornton and J.B. Marion, Thomson Brooks Cole Publishing
5. Classical Mechanics – T.W.B. Kibble and F.H. Bershire, Imperial College Press
6. Theoretical Classical Mechanics – M.R. Spiegel (Schaum's Outline Series), Tata McGraw Hill, New Delhi

Classical Electrodynamics - MPCC-12

Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Electrostatics, Magnetostatics and Maxwell's equations : Revision of basic ideas and equations in electrostatics and magnetostatics, Scalar and Vector potentials, Multipole expansion of the potentials, Maxwell's equations, Electromagnetic (EM) waves, Poynting theorem, Maxwell's stress tensor, gauge transformations, Coulomb and Lorentz gauges, Helmholtz theorem, magnetic monopoles. **7 Lectures**

Relativistic Electrodynamics : Review of Special Theory of relativity, Special Relativity and Maxwell's equations, Invariance of Maxwell's equations under Lorentz transformation (LT), LT as rotation of Minkowski space, concepts of invariant interval, light cone, event and world line, Minkowski diagrams, four-vectors and tensors; Discussions on Four velocity, Four acceleration, Four momentum, Four wave vector, Four force, Four potentials, Four current density in the relativistic framework. Simple applications of four vectors in relativistic particle mechanics, Doppler effect and aberration of light, LT of EM fields, field strength tensor and its dual, Invariant quantities in EM fields, Covariant formulation of Maxwell's equations in tensor notation **18 Lectures**

Radiation : Inhomogeneous wave equations and their solutions by Green's function method, Retarded potentials, Radiation from localized sources and multipole expansion in the radiation zone, Dipole and quadrapole radiation, Radiation from oscillating electric and magnetic dipole, Basic principles of antenna, antenna radiation patterns, Lienard-Wiechart potentials, fields due to a moving point charge – uniform and accelerated motion, Radiation at low velocity, Larmour formula and its relativistic generalization, Radiation when velocity and acceleration are parallel, Bremsstrahlung, radiation when velocity and acceleration are perpendicular, Cyclotron and Synchrotron radiation, angular distribution of radiated power in each case, Cerenkov radiation (qualitative treatment only), radiation reaction, Abraham-Lorentz formula, Thomson scattering, Rayleigh scattering **18 Lectures**

Charged Particle Dynamics in Electromagnetic Fields: Motion of charged particle in uniform static magnetic field, static electric field and crossed electric and magnetic fields, particle drifts, Grad-B drift and curvature drift of charged particles in nonuniform static magnetic fields, adiabatic invariance of magnetic moment of a charged particle and magnetic mirroring, Sokolov-Ternov effect (qualitative discussion) **7 Lectures**

Suggested References:

1. Classical Electrodynamics – J.D. Jackson, John Wiley & Sons
2. Electrodynamics – F. Melia, The University of Chicago Press
3. Classical Electricity and Magnetism – W.K.H. Panofsky, M. Phillips, Addison-Wesley
4. Classical Theory of Fields – L.D. Landau, E.M. Lifshitz, Butterworth-Heinemann
5. Introduction to Electrodynamics – D.J. Griffiths, Pearson Education India
6. Electrodynamics and Classical Theory of Fields and Particles – A.O. Barut, Dover Publications

Mathematical Methods in Physics – MPCC13
Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Second Order Linear Differential Equations With Variable Coefficients: Hypergeometric and confluent hypergeometric functions, Green's function method. **10 Lectures**

Vector Spaces : Elementary Properties in Vector Spaces, Linear vector space, Subspaces, Span, Linear Independence & Dependence, Basis for a vector space, Dimension of a vector space, Transformation from one basis to another, Finite & Infinite dimensional vectors spaces, Real & Complex Vectors spaces – Hilbert space, Fock Space, Complex Projective Space; Linear Mapping, Isomorphism, matrix representation of a linear operator, Similarity, Eigenvalues and Eigenvectors, Diagonalization, Gram-Schmidt procedure of orthogonalization. **8 Lectures**

Integral Equation: Definition, Fredholm equation (first and second kinds), Volterra Equation (first and second kinds); Transformation of second ordered differential equation to integral equations, Solving integral equations: Abel equation, Neumann Series method and Separable Kernels method with examples. **6 Lectures**

Brief Review of Complex Variables: Functions of a complex variable; Analytic functions, Cauchy-Riemann equations, Integration in the Complex plane, Cauchy's theorem, Cauchy's integral formula, Taylor and Laurent expansions, Singular Points and their classification, Branch Point and Branch Cut, Riemann sheets; Residue theorem, application to the evaluation of definite integrals; Integrals involving branch point singularity. **6 Lectures**

Complex Mapping: Transformation of mapping, complex mapping functions, some general transformations, Translation, Rotation, Stretching, Inversion, linear transformation. **5 Lectures**

Abstract Group Theory: Definition. Group postulates. Finite and infinite groups, order of a group, subgroup; rearrangement theorem, multiplication table. Cosets, Lagrange's theorem. Conjugate elements and classes. Invariant subgroups, factor groups. Generators. Isomorphism and homomorphism. Cyclic and other distinct groups. Permutation and alternating groups. Cayley's theorem. **6 Lectures**

Representation Theory: Definition of representation, Faithful and unfaithful representations, Invariant subspaces and reducible representations, Reducible and irreducible representations, Schur's lemmas, great orthogonality theorem and its geometrical interpretation, Character, First and second orthogonality theorems of characters and its geometrical interpretation, Regular representation, celebrated theorem and its implication, Projection operators, determination of basic functions, Direct product groups and their representations, Direct product representations and their reduction, construction of character tables of simple groups. **4 Lectures**

Continuous Group: Infinite groups. Discrete and continuous groups, mixed continuous group, Topological and Lie groups, Axial rotation group SO(2), Rotation group SO(3), Special Unitary groups SU(2). **5 lectures**

Suggested References:

1. Mathematical Methods for Physicists – G.B. Arfken, H.J. Webber, F.E. Harris, Academic Press

2. Complex Variables and Applications – R.V. Churchill and J.W. Brown, McGraw-Hill.
3. Schaum's outline of theory and problems of complex variables with an introduction to conformal mapping and its applications, M.R. Speigel, McGraw-Hill.
4. Complex Analysis – L.V. Ahlfors, McGraw-Hill
5. Matrices and Tensors – A.W. Joshi, Wiley Eastern
6. Group Theory – M. Hammermesh, Addison-Wesley
7. Group Theory and Quantum Mechanics – M. Tinkham, McGraw-Hill
8. Group Theory – A.W. Joshi, Wiley Eastern

Quantum Mechanics I – MPCC14

Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Review of Basics: Schrödinger equation; Wave function and admissible conditions on it; Probability, current density and the continuity equation; General conditions on the potential for admitting bound and scattering states; Superposition and collapse of wave-functions; Observable and expectation values; Exactly solved problems in one dimension — square potential barrier, particle in a box, delta-function potential; concepts of technological applications - Tunneling Electron Microscope (TEM), quantum wells and dots. **6 Lectures**

Fundamental Concepts: Postulates of Quantum Mechanics; Operator and its adjoint; Hermitian and self-adjoint operators; linear, anti-linear, unitary and anti-unitary operators; Dirac notation of state vectors and matrix representation of operators; Orthonormal eigen-kets, Completeness and Closure Relations; Measurements, Observable and the Uncertainty Relation; Discrete and Continuous basis; Eigen-kets of position and momentum operators; Box-normalization; Change of basis; Canonical quantization scheme; coordinate and momentum representation of operators. **10 Lectures**

Quantum Dynamics: Time evolution of quantum systems; energy-time uncertainty relation; Schrödinger, Heisenberg and interaction pictures; Ehrenfest theorem; simple harmonic oscillator (SHO) – stationary state solutions using annihilation and creation operators; Time evolution of SHO; SHO coherent & squeezed states; Propagator and Partition function; propagator of a free particle and SHO; outline of Path-Integral quantization. **10 Lectures**

Quantum System with Many-degrees of Freedom: Particle in a box, isotropic and anisotropic simple harmonic oscillators in three dimensions; Degeneracy of levels; Generalization to many-particle systems; Identical particles; Symmetric and antisymmetric wave functions; Slater determinant; Connection with statistics and implications. **6 Lectures**

Theory of Angular Momentum: Orbital angular momentum; finite and infinitesimal rotations; generators of rotation, their representations and algebra; Euler Rotation; O(3) group; Eigenvalues and eigenfunctions of L^2 and Lz; spherical harmonics; motion in a spherically symmetric potential – hydrogen atom; introduction to spins – operators and eigenstates; SU(2) group; coupling of two angular momenta, Clebsch-Gordon coefficients. **12 Lectures**

Symmetry in Quantum Mechanics: Symmetries, Conservation Laws & Degeneracy; Space and time translations, Rotation; Lattice Translation, Parity and Time-reversal Symmetry, Kramers degeneracy. **6 Lectures**

Suggested References:

1. Quantum Mechanics – D.J. Griffiths, Pearson Education India.
2. Modern Quantum Mechanics – J.J. Sakurai, Pearson Education India.
3. Non-Relativistic Theory: Course of Theoretical Physics, Vol. 3 – L.D. Landau and E.M. Lifshitz, Elsevier India.
4. Quantum Mechanics – L.I. Schiff, Tata-McGraw-Hill Education
5. Principles of Quantum Mechanics – R. Shankar, Springer.
6. Quantum Mechanics: Concepts and Applications, N. Zettilli, John Wiley & Sons
7. A Txtbook of Quantum Mechanics – Mathews and Venkatesan, Tata-McGraw-Hill

8. Quantum Mechanics – B.H. Bransden, C. J. Joachain, Pearson Education India.
9. Quantum Mechanics, Vol. I, II – C. Cohen-Tannoudji, B. Diu, F. Laloe, Wiley-VCH.

Quantum Mechanics II – MPCC21
Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Approximate Methods: Classical limit of Schrödinger equation and Hamilton-Jacobi equation; WKB approximation - application to potential barrier (α decay), harmonic oscillator problem; Variational method - applications. **6 Lectures**

Time-Independent perturbation theory: Introduction; Non-degenerate and degenerate cases; Anharmonic oscillator with cubic and quartic terms; Zeeman effect, Stark effect; spin-orbit coupling and alkali atoms; singlet and triplet states of helium atom. **6 Lectures**

Time-Dependent Perturbation Theory: Exactly solved Time-dependent two-state problem: Nuclear Magnetic Resonance; Dyson series; Transition rates; Constant and Harmonic Perturbation; Applications to interactions with the classical radiation field; Fermi's golden rule, electric dipole approximation, absorption cross-section, spontaneous and stimulated emission of radiation. **8 Lectures**

Scattering Theory: The general formalism (Lab and CM frames, cross sections); Integral equation of scattering; Green's function; Born approximation; Condition for validity of Born approximation; Scattering from Yukawa and Coulomb potential; Spherical potential; Partial wave analysis and phase-shifts; Optical theorem; Scattering by a rigid sphere; Effective range and scattering length (S-wave only); Eikonal approximation; Cross-sections for scattering of identical particles. **10 Lectures**

Relativistic Quantum Mechanics: Inadequacy of Klein-Gordon equation; Dirac equation; Algebra of Dirac matrices; Plane wave solutions; Prediction of antiparticles; Spin of electron and Pauli spin matrices; Pauli equation; Magnetic moment of the electron; Relativistic Hydrogen atom and its Non-relativistic limit; Covariant form of Dirac Equation; Parity, charge conjugation, time reversal operation; Shortcomings of Dirac equation. **12 Lectures**

Modern Developments: Adiabatic Theorem & Geometric Phases**;** Berry Phase; Bohm-Aharonov Effect; Applications; EPR paradox, Bell's Inequality; quantum entanglement; No-Clone Theorem; Schrodinger's Cat, Quantum Zeno Paradox. **8 Lectures**

Suggested References:
1. All the books referred for course of Quantum Mechanics I (MPCC14).
2. Feynman Lectures of Physics, Vol. III, R.P. Feynman, Pearson Education India.
3. Advanced Quantum Mechanics, J.J. sakurai, Pearson Education India.
4. A First Book of Quantum Field Theory – A. Lahiri and P.B. Pal, Narosa Publishing House.
5. The Quantum Revolution, Vol I and Vol III – G. Venkataraman, University Press.
6. Quantum Mechanics: A Modern Development, L.E. Ballentine, World Scientific.
7. Quantum Mechanics: Concepts and applications, N. Zettilli, John Wiley & Sons.

Statistical Mechanics – MPCC22
Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Basic Concepts: Random walk and statistical basis of thermodynamics; phase space and ensembles; Liouville's theorem. **3 Lectures**

A Brief Review: Key points of Micro canonical and Canonical ensembles **5 Lectures**

Grand Canonical Ensemble: Equilibrium between a system and a heat reservoir; density and energy fluctuations in the grand canonical ensemble; critical opalescence; applications. **5 Lectures**

Quantum Statistical Mechanics: Density matrix; density matrix for different ensembles, applications; Bose-Einstein and Fermi-Dirac distributions, Statistics of occupation numbers. **5 Lectures**

Ideal Bose System: Thermodynamic behaviour of an ideal Bose gas; Bose-Einstein condensation; Liquid helium; Bose condensation in gases, phonons. **5 Lectures**

Thermodynamic Behaviour of an Ideal Fermi Gas: A degenerate electron gas; white dwarf and Chandrasekhar limit, magnetic behaviour of an ideal Fermi gas. **5 Lectures**

Chemical Reaction: The condition for chemical equilibrium; the law of mass action; ionization equilibrium; Saha ionization formula. **4 Lectures**

Imperfect Gas: Cluster expansion for classical gas; Calculation of partition function for low densities; equation of state, virial coefficients; Van der Waal's equation. **5 Lectures**

Phase Transitions and Critical Phenomena: Qualitative description and classification of phase transitions; Ising model and lattice gas; critical exponents; order parameter, correlation function, fluctuation dissipation theorem; scaling hypothesis and scale invariance. **6 Lectures**

Introduction to Non-equilibrium Phenomena: Introduction to Stochastic Processes, Diffusion and Brownian motion, Langevin equation, Fokker-Planck equation – basic derivation, application to Barrier Crossing Problem. **7 Lectures**

References:

1. Statistical Mechanics – R.K. Patharia, P. D. Beale, Academic Press
2. Statistical Mechanics – K. Huang, John Wiley and Sons
3. Fundamentals of Statistical and Thermal physics – F. Reif
4. Statistical Physics (V) – L.D. Landau and E.M. Lifshitz, Elsevier
5. Statistical Mechanics and Properties of matter – E.S.R. Gopal, Ellis Horwood
6. Statistical Mechanics – B.K. Agarwal and M. Eisner
7. Non-equilibrium Statistical Mechanics – R. Zwanzig, Oxford University Press, 2001.
8. Relaxation Phenomena in Condensed Matter Physics – S. Dattagupta, Academic Press

Solid State Physics – MPCC23

Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Imperfection in Crystals: Introduction to imperfections / defects in crystal, Point defects, Schottky defects, Frenkel defects, diffusion, Fick's law, color centre, line defects, dislocations, order-disorder phenomena. **5 Lectures**

Electronic Properties of Metals: Statistics of free electron gas, heat capacity of electron gas, electron scattering and source of resistance, variation of resistivity with temperature, thermal conduction, Wiedemann-Franz Law, motion of electrons in static electric and magnetic fields, Hall effect, magnetoresistance, thermionic emission, Schottky effect. **8 Lectures**

Thermal Properties of Solids: Specific heat capacity of solids, Debye approximation and its experimental verification, Born cut-off procedure, Gruneissen relation, anharmonicity, thermal expansion, thermal conductivity of solids & lattice, Umklapp process. **8 Lectures**

Band Theory of Solids: Periodic potential and Bloch's theorem, weak potential approximation, density of states in different dimensions, energy gaps, Fermi surface and Brillouin zones. Origin of energy bands and band gaps, effective mass, tight-binding approximation and calculation of simple band-structures. Motion of electrons in lattices, Wave packets of Bloch electrons, semi-classical equations of motion, motion in static electric and magnetic fields, theory of holes, cyclotron resonance. **8 Lectures**

Boltzmann Transport Equation and Application: Distribution function, Boltzmann Transport Equation, Collision Integral, Electrical conductivity. **3 Lectures**

Physics of Semiconductors: Intrinsic and extrinsic semiconductors, carrier statistics in intrinsic and extrinsic semiconductors, expression for Fermi levels, recombination processes, direct and indirect band gap semiconductors. **5 Lectures**

Magnetism: Hund's rule, Rare Earth, Iron group ions, quenching of orbital angular momentum, van vleck paramagnetism, Pauli spin paramagnetic susceptibility; Ferromagnetism - Electrostatic origin of magnetic interaction, Heisenberg's exchange interaction, domains, domain-wall and energy, Ferrimagnetism, antiferromagnetism. **8 Lectures**

Superconductivity: Review of basic properties, London' equation and superconductor under ac field, Thermodynamics of superconducting state, idea of BCS theory, Cooper pair, flux quantization, Josephson effect, High Tc superconductors. **5 Lectures**

Suggested References:

1. Introduction to Solid State Physics – C. Kittel, Wiley Eastern ASG AB
2. Solid State Physics – A.J. Dekker, Macmillan India Ltd. AB
3. Solid State Physics – H. Ibach, H. Luth, Springer-Verlag AB
4. Introduction to the Theory of Solid State Physics – J.D. Patterson, Addison-Wesley AB
5. Solid State Physics – S.O. Pillai, New Age International Publishers ASG AB
6. Solid State Physics – N.W. Ashcroft, N.D. Mermin, Brooks / Cole ASG
7. Principles of the Theory of Solids – J.M. Ziman, Cambridge University Press. ASG

Electronics – MPCC24

Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Semiconductor devices:(from the point of view of band structure, variation of electrical field across the junction etc.) homo and hetero junction devices, metal semiconductor junctions: Schottky barriers; rectifying contacts; ohmic contacts, miscellaneous semiconductor devices: Tunnel diode; Photodiode; Solar cell; LED; LDR, MOS-capacitors; capacitance voltage characteristics of MIS structure, C-V characteristics of various junctions. **8 Lectures**

Transducer Sensor and Detector:, Transducers, Characteristics of Transducers. Transducers as electrical element and their signal conditioning. Temperature transducers: RTD, Thermistor, Thermocouples, Semiconductor type temperature sensors (AD590, LM35, LM75) and signal conditioning. Linear Position transducer: Strain gauge, Piezoelectric. Inductance change transducer: Linear variable differential transformer (LVDT), Capacitance change transducers. Proximity sensors: Capacitive, Inductive, Magnetic, Optical; **10 Lectures**

Power supply: Linear regulator Vs. Switching regulator, Topologies of SMPS – isolated and non isolated topologies, DC-DC converters: Buck, Boost, Buck-Boost, Cuk, polarity inverting topologies – push pull and forward converters, half bridge and full bridge with continuous and discontinuous mode, Input & output filter design, multi-output boost converters, Fly back converters, Voltage fed and current fed topologies; EMI issues. **7 Lectures**

Filters: definition, constant-K type low pass and high pass filter-characteristic impedance – its derivation of expression for T and Pi type symmetrical Four Terminal Network. Propagation constant and its derivation for T and Pi type symmetrical FTN – LPF and HPF analysis, cut-off frequency, drawbacks of prototype constant-K filters. **5 Lectures**

Microwave diodes: Gunn and IMPATT diodes – introduction, RWH mechanism for Gunn action, modes of bulk device and modes of Gunn diode, derivation of criterion for Gunn oscillation; IMPATT diode – introduction, source of DNR; Read diode - avalanche zone analysis of Read diode, drift zone analysis- power-frequency limitation. **5 Lectures**

Basics of Radar: Pulsed radar – Range equation, implications of range equation, maximum and minimum range; Doppler radar – moving target indicator radar, CW radar, FM radar and FM altimeter, blind speed of radar. **5 Lectures**

Phase lock loop: differential equation for first order loop, FM demodulation, mathematical modeling of PLL, Derivation of 2^{nd} order PLL equation, steady state output voltage and phase error of 2^{nd} order PLL. FM signal demodulation in 2^{nd} order PLL. **5 Lectures**

Transmission line: primary constants, Derivation of Telegrapher's equation, expressions for voltage and current on the line, input impedance of the line, sources of distortion and distortionless propagation, fault location on the line. **5 Lectures**

Suggested References:

1. Solid State Electronic Devices – B.G. Streetman, S. Banerjee, Pearson Education.
2. An Introduction to Semiconductor Devices – D.A. Neamen; McGraw Hill

3. Physics of Semiconductor Devices – S.M. Sze, Wiley
4. Advanced Electronics – T. Chattopadhyay, CBS Publishers & Distributors
5. Network, lines and fields – J.D. Ryder
6. Telecommunications – W. Fraser
7. Phaselock Techniques – F.M. Gardner, John Wiley & Sons
8. Advanced DC-DC converters – F.L. Luo, H. Ye, CRC Press.
9. Dynamic Analysis of Switching-Mode DC/DC Converters – A. Kislovski, Springer
10. DC-DC Power Converter Design & Implementation – I. Jamil, GRIN Publishing.
11. Sensors and Transducers – D. Patranabis, Prentice-Hall of India
12. Sensors and Transducers: Characteristics, Applications, Instrumentation – M.J. Usher, D.A. Keating; MacMillan.
13. Transducers and Instrumentation – D.V.S. Murty, Prentice-Hall of India

Atomic and Molecular Physics - MPCC31

Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

One Electron Atoms: Review of Non-relativistic theory and the Dirac theory of the hydrogen atom, Expansion of the Dirac Hamiltonian in powers of v/c and fine structure, Lamb shift, Hyperfine structure and Isotope shifts, alkali spectra and elementary ideas of quantum defects, Rydberg and Exotic atoms. **5 Lectures**

Two-Electron Atoms: Para and Ortho states, role of spin in two-electron atoms and Pauli's Exclusion Principle, Perturbation and Variational approximations for the two-electron atoms. Doubly excited states of two-electron atoms, Autoionisation, Auger effect. **5 Lectures**

Many-Electron Atoms: Central field approximation, periodic system of elements, Thomas - Fermi model, Hartree-Fock method and the self-consistent field, correction to the central field approximation - L-S and J-J coupling, origin of X-ray spectra. **10 Lectures**

Interaction of Atoms with Radiation: Selection rules, Line intensities and lifetime of excited states, Line shapes and widths, Pressure and Doppler broadening, Photoelectric effect, atoms in external static fields: Zeeman, Paschen-Bach and Stark effects. **5 Lectures**

Molecular Structure: General nature of molecular structure, Rotational, Vibrational and electronic motion, Born-Oppenheimer separation of electronic and nuclear wave functions, LCAO method and the -ion, Heitler-London method for H_2 molecule, recoil effect in emission and absorption, Mossbauer effect. **5 Lectures**

Molecular Spectra: Rotational energy levels of diatomic molecules, vibrational, rotational sprctra of molecules, anharmonic oscillator models for diatomic molecules, pre-dissociation and Dissociation, Rayleigh Law, Raman scattering, electronic spectra of diatomic molecules, Deslandre's table, Fortrat diagram, Franck-Condon principle, Fluorescence, Phosphorescence, electronic spin and Hund's coupling cases, Effect of nuclear spin on diatomic molecules, inversion spectrum of Ammonia. **12 Lectures**

Laser: Population Inversion, Spatial and Temporal coherence, Ammonia Maser and He-Ne Laser, Tunable lasers, Laser cooling of atoms. **4 Lectures**

Magnetic Resonance Spectroscopy: Principle of magnetic resonance, Electron spin resonance and Nuclear magnetic resonance, Chemical shifts. **4 Lectures**

Suggested References:

1. Physics of Atoms and Molecules – B H Bransden and C J Joachain, Pearson India
2. Fundamentals of Modern Physics – Robert Eisberg, John-Wiley
3. Introduction to Molecular Spectroscopy – Gordon Barrow McGraw Hill
4. Molecular Spectra and Molecular Structure: Spectra of Diatomic Molecules – Gerhard Herzberg (R.E. Krieger Publishing Company)
5. Chemical Applications of Group Theory – Frank Albert Cotton (John Willey & Sons)
6. Fundamentals of Molecular Spectroscopy – C N Banwell and Elaine M McCash (McGrawHill, Indian edition)

Nuclear and Particle Physics – MPCC32
Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Tools for Nuclear and Particle Physics: Particle accelerators - linear and circular; brief idea of Pelletron, Tevatron, LHC; passage of particles and radiation through matter – gaseous, scintillation and solid state detectors with examples of particle detection; outline of complex detectors in Nuclear and Particle Physics – INGA, CMS, MAGIC **5 Lectures**

Fundamental Interactions – Introduction to Electromagnetic, Weak, Strong and Gravitational interactions – mediators, strength and range; introduction to the Standard Model and its particle content, classification of elementary particles, doublets of weak interaction; quark model of hadrons, classification of hadrons, Gellmann-Okubo mass formula; symmetry and conservation laws, Baryon and Lepton numbers; elementary ideas of CP and CPT invariance, Weak CP violation in kaons; Lie algebra, SU(2)-SU(3) multiplets; unification of forces.
10 Lectures

General properties of nuclei: Constituents of the nucleus, nuclear charge, mass and binding energy, nuclear radius, spin, parity and statistics, Coulomb energy of mirror nuclei, nuclear size from electron scattering experiments, magnetic dipole moment and electric quadrupole moment. **5 Lectures**

Two-body problems: Characteristics of nuclear forces, tensor forces and exchange forces, nucleon-nucleon potential ground state of the deuteron, excited state of the deuteron. Two-body scattering: Kinematics, cross-sections, low energy n-p scattering, singlet and triplet scattering, coherent scattering of neutrons by ortho- and para-hydrogen, low energy p-p scattering, charge independence and charge symmetry of nuclear forces. **5 Lectures**

Nuclear Decay:
(a) Alpha decay - Systematics of α decay, barrier penetration, Gamow's theory of α decay, Geiger-Nuttal law, fine structure of alpha spectra. (b) Beta decay - $\beta+$ and $\beta-$ emissions and electron capture, neutrino and antineutrino, Fermi's theory of β decay, Kurie plots, comparative half-life, allowed and forbidden transitions, selection rules in beta decay, Non-conservation of parity in beta decay. (c) Gamma decay - γ ray spectra, multi-pole moments, transition probabilities, selection rules, internal conversion, pair production. **7 Lectures**

Nuclear models: Liquid drop model and nuclear fission, Bethe-Weizsacker semi-empirical mass formula, stability of nuclei, Nuclear shell model (single-particle), magic numbers, magnetic moments and Schmidt lines, Collective Model of Bohr and Mottelson. **7 Lectures**

Nuclear reactions: Nuclear reaction kinematics, Q-value equation, threshold energy and cross section of nuclear reactions, resonance scattering and reactions, direct reactions, Heavy ion reactions. **5 Lectures**

Neutrino Physics - Sources of neutrinos, probes for Astrophysics; detection of neutrinos, neutrino experiments – Homestake, Super-Kamiokande, SNO, IceCube; introduction to solar neutrino problem, and neutrino oscillation; Majorana neutrino and neutrinoless double beta decay (qualitative discussion) **6 Lectures**

Suggested References:

1. Nuclear Physics: Theory and Experiment – R.R. Roy and B.P. Nigam, New Age International Publishers
2. Introductory Nuclear Physics – Kenneth S. Krane, John Wiley and Sons Ltd
3. Atomic and Nuclear Physics (Vol.-2) – S.N. Ghosal, S. Chand & Co.
4. Techniques for Nuclear and Particle Physics Experiments – W.R. Leo, Springer-Verlag
5. Introduction to Elementary Particles - D.J. Griffiths, Wiley-VCH
6. Introduction to High Energy Physics - D.H. Perkins, Wiley-VCH

Relativistic Mechanics and Field Theory – MPCC33

Core Course; Lectures – 50 Hours, Tutorial – 10 Hours

Tensor Analysis: Coordinate transformation - scalar, vector, tensor & spinor, covariant, contravariant and mixed tensors, addition, subtraction, outer product, inner product and contraction, symmetric and antisymmetric tensors, quotient law, metric tensor - length, curvature & torsion, raising and lowering of indices, Minkowski metric, four-vector notation, Kronecker delta & Levi-Civita tensors, tensor calculus. **10 Lectures**

Relativistic Particle Mechanics: Natural unit and mass dimension, frame of reference, Galilean transformation, basic postulates of special theory of relativity, Lorentz transformation and its consequences, relativistic dynamics, Lagrangian and Hamiltonian of relativistic particles, equation of motion of free relativistic particles, motion of relativistic particle in presence of electromagnetic field, Compton scattering, Doppler effect. **10 Lectures**

Continuous System and Classical Fields: Motivations, transition from discrete to continuous system, examples-coupled spring system, coupled spin-chain & sigma model, action functional and equations of motion, symmetries and conservation laws: Nöether's Theorem, space-time and internal symmetries, Hamiltonian formalism, time-evolution, Poisson bracket, description of classical fields - scalar, vector, spinor and tensor fields. **12 Lectures**

Application of Field Theory Models: Motivation, Derrick's theorem, nonlinear Schrödinger equation, domain wall in ϕ^4 theory, sine-Gordon equation, hydrodynamics & introduction to Navier-Stokes equation. **8 Lectures**

Introduction to Second Quantization: Schrödinger field, equivalent many-body system, eigenstates, Klein-Gordon field as collection of harmonic oscillators, normal ordering, causality, Klein-Gordon propagator, quantization of complex scalar field, outline of quantization of vector and spinor fields. **10 Lectures**

Suggested References:

1. A Students Guide to Vectors and Tensors – D. Fleisch, Cambridge University Press.
2. Tensor Calculus – J.L. Synge, A. Schild, Dover Publications.
3. Classical Mechanics – H. Goldstein, Pearson Education
4. Special Relativity and Classical Field Theory – L. Susskind, A. Freidman, Penguin
5. The Classical Theory of Fields: Vol. 2 – L.D. Landau and E.M. Lifshitz, Butterworth-Heinemann.
6. Relativistic Quantum Fields – J.D. Bjorken, S.D. Drell, Dover Publications.
7. Quantum Field Theory – C. Itzykson and J.B. Zuber, Dover Publications.
8. A First Book of Quantum Field Theory – A. Lahiri and P.B. Pal, Narosa Publishing House.
9. Solitons & Instantons – R. Rajaraman, North-Holland.

General Laboratory I – MPCC15
Core Course; 90 Hours

1. Solving 2nd order differential equation using OP-AMP
2. Design of Colpitts oscillator/RF oscillator using transistor
3. Design of Hartley oscillator/RF oscillator using transistor
4. Study of magneto-optic rotation using Faraday rotation set up.
5. Study of electro-optic rotation using Pockel's effect set up.
6. Measurement of the absorptive coefficient of a substance (Liquid phase) for a particular wavelength.
7. Dielectric constants of liquids
8. Franck – Hertz experiment
9. Charge-mass ratio (e/m) by Zeeman effect (Fabry Perot Etalon)
10. Magnetic Hysteresis loop tracer
11. Calibration of thermocouple using PT100 sensor

More experiments will be added.

General Laboratory II – MPCC34
Core Course; 90 Hours

1. Measurement of magnetoresistance.
2. Study of temperature dependence of Hall coefficient.
3. Study of the dispersion relation for the monoatomic and diatomic lattices.
4. Study the temperature dependence of dielectric constant of a ferroelectric crystal.
5. Characteristics of a PN junction, determination of reverse saturation current, material constant, temperature co-efficient of junction voltage, etc.
6. Determination of velocity of sound in liquids – Ultrasonic Interferometer method.
7. α-spectroscopy
8. β-spectroscopy
9. γ-spectroscopy
10. MCA based spectroscopy

More experiments will be added.

General Laboratory III – MPCC41
Core Course; 90 Hours

1. Magnetostriction using Michelson interferometer.
2. Faraday Effect experiment (optical rotation due to magnetic field) with optical bench, 2 mW He-Ne laser.
3. Numerical aperture and attenuation constant of optical fibre.
4. Study of Fabry-Perot Interferometer.
5. Study of emission spectra of metals.
6. Study of Coupled Oscillator.
7. Determination of thermal expansion of metals using Fizeau's interferometer.
8. Determination of Young's modulus of glass/perspex using Cornu's method.
9. Study of acoustic diffraction.
10. Study of iodine spectra and determination of dissociation energy of iodine molecule.
11. Determination of separation of D1 and D2 lines using Michelson interferometer.
12. Study of light propagation through optical fibre using LASER.

More experiments will be added.

Computational and Numerical Methods in Physics – MPCC25

Core Course, 90 Hours

Review: Interpolation & Extrapolation, root finding, integration & differential equation; Computational errors and propagation of errors.

Matrix Manipulation: Addition and multiplication of matrices, Seidal method of matrix inversion, numerical solution of simultaneous linear equations: Gaussian elimination, eigenvalues and eigenvectors.

Fast Fourier Transform: Fourier Transform, Fast Fourier Transform (FFT), FFT of some real functions, FFT in higher dimensions, Fourier Transform of real data, spectral applications.

Monte Carlo Simulation: Random number generation and quality, Monte Carlo Integration – simple examples, metropolis algorithm and its application - Ising spin system, simple problem in statistical mechanics.

Ordinary Differential Equation: Runge-Kutta and other multi-step methods, stiff differential equation, applications to dynamical systems, example: Lorenz equations, stochastic differential equation, solution of simple systems.

Boundary-value problem: Shooting method, relaxation method, Examples: Stationary Schrödinger equation of harmonic and anaharmonic oscillators in one dimension, spheroidal harmonics.

Partial Differential Equations: Introduction, initial-value problem, example: wave-equation in one dimension.

Multivariate Analysis: Introduction to different multivariate analysis methods, simple exercises.

References:

1. Computational Mathematics, B.P. Demidovich, I.A. Maron and G. Yankovski (Translator), Central Books Limited
2. An Introduction to Numerical Analysis, K E Atkinson, John Wiley & Sons.
3. Numerical Recipes in C, W.H. Press, S.A. Teukolsky, W.T. Vallering and B.P. Flannery, Cambridge University Press.
4. Numerical Methods in Physics, A.L. Garcia, Amazon Digital Services (Revised edition).
5. A first course in Computational Physics, P.L. De Vries, John Wiley & Sons.

Elective Courses (MPEC35, MPEC42, MPEC43, MPEC44)
Dissertation (MPDC45)

A list of topics for the Dissertation Course (MPDC4) to be offered by the department will be announced at the beginning of Semester-III. Students have to provide their choice of topics. The distribution of topics to students will be however decided by the faculty members.

Similarly, a list of Elective Courses to be offered by the department for each academic session, decided by the faculty members will be declared at the beginning of Semester-III. Students have to select 4 Elective Courses (as MPEC1 for Semester-III and MPEC2, MPEC3 and MPEC4 for Semester-IV) from the declared list of courses. The maximum number of students for each Elective Course will be decided by the department.

Topics in Modern Quantum Mechanics – E01

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Path Integrals in Quantum Mechanics: Paths in classical mechanics; path integrals as the sum over paths; Feynman's formulation of path integral quantization; quantization of simple harmonic oscillator & a few simple systems; Aharonov-Bohm effect & path integrals; canonical versus path integral quantization; perturbation theory; example - anharmonic oscillator; scattering; example-scattering of an electron by an atom; path integral representation of the partition function; example-harmonic oscillator & a few simple systems; A brief overview on the applications of the technique to quantum field theory . **20 Lectures**

Supersymmetric Quantum Mechanics(SUSY QM): Hamiltonian formulation of SUSY QM; State space structure of supersymmetric harmonic oscillator; Broken SUSY; Factorization & hierarchy of Hamiltonians; Shape invariance & solvable Potentials; Supersymmetric WKB approximation; Quantization condition for broken and unbroken SUSY; SUSY & Dirac Equation; SUSY & the Dirac particle in a Coulomb field. SUSY and path integrals. **15 Lectures**

Quantum Entanglement: Qubit; spin-½ & Bloch sphere; density operator; pure vs. mixed ensemble; correlation in spin singlet state; Einstein's locality principle and hidden variables; the Bell inequality; quantum entanglement; Schmidt decomposition; experiments & loopholes; usage of entanglement : dense coding, quantum teleportation etc. **10 Lectures**

Quantum Information Theory: Classical information theory; Shannon entropy; quantum information-types and channels; von Neumann entropy and its properties; no-cloning theorem. **5 Lectures**

Suggested References:

1. Quantum Mechanics and Path Integrals – R.P. Feynman, A.R. Hibbs (emended by Daniel F. Styler), Dover Publications.
2. Techniques and Applications of Path Integration – L.S. Schulman, Dover Publications.
3. Path Integral in Quantum Mechanics – J. Zinn-Justin, Oxford University Press.
4. Supersymmetry and Quantum Mechanics – F. Cooper, A. Khare and U. Sukhatme, Physics Reports 251 (1995) 267 [hep-th/9405029];
5. Supersymmetry in Quantum Mechanics – F. Cooper, A. Khare and U. Sukhatme, World Scientific
6. Modern Quantum Mechanics (Revised Edition) – J.J. Sakurai, Pearson Education India
7. Quantum Computation and Quantum Information, M.A. Nielsen and I.L. Chuang, Cambridge University Press.
8. Lecture notes on Quantum Entanglement, J. Preskill, http://www.theory.caltech.edu/preskill/ph229/

Quantum Field Theory – E02
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Lorentz Group: Lorentz transformations; Classification of Lorentz Transformations; Generators; Lorentz Group; Representation of Lorentz group; Poincaré group; Lorentz invariant field theory. **7 Lectures**

Canonical Quantization of free fields: Inadequacies of quantum mechanics and the necessity of quantum field theory; Second quantization; real and complex scalar fields; spinor field; electromagnetic field; parity, charge conjugation and time-reversal operators; translation and angular momentum operators; propagators. **15 Lectures**

Interacting quantum fields: Interaction Picture; Perturbation theory; S-matrix; Wick's theorem; Feynman diagram and rules; Applications to Two-body scattering processes: Rutherford, Bhabha, Möeller, Compton and electron-muon scattering, pair creation and annihilation processes; calculation of cross-section for a QED scattering process. **10 Lectures**

Regularization and Renormalization: Basic concepts; degree of divergence; cut-off and dimensional regularization; mass and charge renormalization. **5 Lectures**

Gauge Theories: Global and local gauge transformations; Abelian and non-abelian gauge fields; O(3) and SU(2) invariant gauge theories; Spontaneous Symmetry Breaking; Higgs mechanism; Brief introduction to QCD and asymptotic freedom. **8 Lectures**

Solitons in models of Field Theory: Solitons, Derrick's theorem, domain wall, Sine-Gordon equation, vortex solutions, `t Hooft-Polyakov monopole. **5 Lectures**

Suggested References:

1. Relativistic Quantum Fields – J.D. Bjorken, S.D. Drell, Dover Publications.
2. Quantum Field Theory – C. Itzykson and J.B. Zuber, Dover Publications.
3. Introduction to Quantum Field Theory – M.E. Peskin, D.V. Schroeder, Addison-Wesley
4. Quantum Field Theory – L.H. Ryder, Cambridge University Press.
5. Lecture Notes by D. Tong: www.damtp.cam.ac.uk/user/tong/qft.html
6. A First Book of Quantum Field Theory – A. Lahiri, P.B. Pal, Narosa Publishing House.
7. Notes from Sidney Coleman's Physics 253a, S. Coleman, arXiv:1110.5013
8. Introduction to Elementary Particles, D.J. Griffiths, John Wiley & Sons.
9. Quantum Field Theory: A Modern Introduction – M. Kaku, Oxford University Press.
10. Solitons & Instantons – R. Rajaraman, North-Holland.

Statistical Methods in Physics – E03

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Introduction to Probability and Statistics: Event, Observation and Measurement, Outcome spaces and events, Assignment of Probabilities to Events, Axioms of probability, Conditional Probability, Independence, and Bayes' Theorem, Random Events and Variables, **4 Lectures**

Probability Distributions and Their Properties: Discrete and Continuous Distributions, Expected values: mean, variance, skewness, kurtosis, Moment generating function, Some important distributions (Binomial Distribution, Poisson Distribution, Uniform Distribution, Normal Distribution, Log-normal distribution, Exponential Distribution, Chisquare Distribution, Gamma Distribution, Student's t Distribution), Multivariate probability densities **8 Lectures**

Measurement Uncertainties: Definition of measurement and its uncertainties, statistical and systematic uncertainty, error propagation, Averaging correlated/uncorrelated measurements, biased measurements **4 Lectures**

Statistical Inference: Concepts of statistical inference, Maximum Likelihood method for parameter inference, Method of moments, Method of Least Squares, Linear Regression, confidence intervals; Resampling methods – Jackknife & Bootstrap; Hypothesis testing techniques - Significance level and P-values; Model selection and Goodness of Fit tests (Chi-square test, Likelihood ratio test, Kolmogorov-Smirnov test, Student's t test, F test); Bayesian statistical inference. **12 Lectures**

Data Smoothing, Density Estimation: Concept of density estimation, Histograms, Kernel density estimators, Adaptive smoothing, Nonparametric regression **4 Lectures**

Multivariate Analysis: Concepts of Multivariate Analysis, Multivariate distances, Multivariate Normal distribution, Multiple Linear Regression, Principal Component Analysis, Factor and Canonical Correlation analysis, Outliers and robust method **8 Lectures**

Clustering, Classification and Data Mining: Concepts of clustering and classification, Agglomerative hierarchical clustering, k-means clustering, Multivariate normal clusters, Linear discriminant analysis, Classification trees, Nearest-neighbor classifiers, Artificial neural networks, Random Forest **10 Lectures**

Suggested References:

1. Probability, Random variables & Random processes – H.P. Hsu, Schaum's outline series, McGraw-Hill
2. Theory of probability and Random Process – L.B. Koralov, Y.G. Sinai, Springer
3. Mathematical Statistics: A Unified Introduction – G.R. Terrell, Springer
4. Statistical Challenges in Astronomy – E.D. Feigelson, G.J. Babu, Springer

General Theory of Relativity – E04

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Riemannian Geometry: Vectors and Tensors; parallel transport, covariant differentiation; Geodesics; Riemann-Christoffel curvature tensor - its symmetry properties, Ricci tensor; Bianchi identities; vanishing of the curvature tensor as a condition for flatness, Geodesic deviation equation, Lie derivatives; space-time symmetries, Killing vectors. **14 Lectures**

Principle of general covariance and principle of equivalence; Einstein field equations, derivation from a variational principle. **4 Lectures**

Schwarzschild Exterior Solution: Birkhoff's theorem, Geodesics in a Schwarzschild geometry. Crucial tests of general relativity - perihelion shift, bending of light, gravitational redshift. Schwarzschild blackhole - event horizon and static limit, Kruskal-Szekere's diagram. **10 Lectures**

Schwarzschilds Interior Solution: Tolman-Oppenheimer-Volkov equation; Collapse of stars; Reissner-Nordstrom solutions - charged black hole, extremal black holes, Kerr-Newman solutions, Kerr-Newman black holes. Ergosphere, Penrose process and extraction of energy from a black hole. **10 Lectures**

Energy conditions; anisotropies; vorticity and shear; Raychaudhuri equation; Singularity theorems of Hawking and Penrose (Qualitative discussion only) **8 Lectures**

Linearized field equations and gravitational waves. **4 Lectures**

Suggested References:

1. Lecture on General Relativity and Cosmology – J.V. Narlikar, Macmillan (India)
1. Introduction to General Relativity – R. Adler, M. Bazin and M. Schiffer, McGraw-Hill.
2. A First Course in General Relativity – B.F. Schutz, Cambridge University Press.
3. Gravitation – C.W. Misner, K.S. Thorne and J.A. Wheeler, W.H. Freeman & Co
4. Spacetime and Geometry: An Introduction to General Relativity – S. Caroll, Addison-Wesley.
5. Introducing Einstein's Relativity – R. D'Inverno, Oxford University Press
6. Gravity: An Introduction to Einstein's General Relativity – J.B. Hartle, Pearson
7. Gravitation and Cosmology : Principles and Applications of the General Theory of Relativity – S. Weinberg, John Wiley & Sons
8. General Theory of Relativity – A.K. Raychaudhuri, S. Banerjee, A. Banerjee, Springer

Cosmology – E05

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Introduction to Cosmology: Hubble's law, Cosmological Principle, observational basis for cosmological theories, a brief introduction to big bang cosmology. **5 Lectures**

Homogeneous Isotropic World Models: Derivation of Friedmann models and their properties, radiation dominated and matter dominated universe, Open and closed Universe model, the distance scale, age of the universe, cosmological parameters, Lambda CDM model **8 Lectures**

Physics of the Big Bang: Thermal history of the universe, cosmological baryogenesis, Shakharov conditions, cosmological nucleosynthesis **8 Lectures**

Cosmic Microwave Backgroud Radiation: Origin of CMBR, the decoupling era, Saha Ionisation equation, Evolution of neutral fraction before the recombination era, Anisotropies in CMBR, Dipole anisotropy, primary and secondary anisotropies in the CMBR, Angular power spectrum and estimation of cosmological parameters, Silk damping **7 Lectures**

Achievements and Problems of the Standard Model: horizon problem, flatness problem, coincidence problem, monopole problem, entropy problem, inflation, Different models of inflation, dark energy **6 Lectures**

Galaxy: Milky Way as a galaxy, galaxy types, classification and morphology of galaxies, dynamics of galaxies, rotation curves and dark matter, galaxy properties, scaling relations (qualitative discussion only) **5 Lectures**

Large Scale Structure Formation: Inhomogeneities in the universe, gravitational instability, linear theory for description and evolution of density fluctuations, non-linear structure formation, Spherical collapse approximation, Halo model of structure formation, Zeldovich approximation, N-body simulations (qualitative discussion only) **6 Lectures**

Large Scale Structures of the Universe: Redshift surveys of galaxies, measures of the galaxy distribution, correlations functions and power spectra, Cosmic web (qualitative discussion only) **5 Lectures**

Suggested References:

1. Principles of Physical Cosmology – P.J.E. Peebles, Princeton University Press, 1993
2. Cosmological Physics – J.A. Peacock, Cambridge University Press, 1998
3. Cosmology – S. Weinberg, Oxford University Press, 2019
4. Modern Cosmology – S. Dodelson, Academic Press, 2003
5. The Early Universe – E.W. Kolb, M.S. Turner, Taylor & Francis, 1994
6. Introduction to Cosmology – J.V. Narlikar, Cambridge University Press, 2002
7. Theoretical Cosmology – A.K. Raychaudhuri, Oxford University Press, 1979

Astrophysics – E06

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Basic concepts of Astronomy: Celestial sphere and related topics, Celestial coordinate systems; Explanation of astronomical events; Distance measurement in astronomy. Measurement of masses and radii of stars, Binary stars, and description of a binary system. **10 Lectures**

Stellar Evolution: Star formation, stellar magnitudes, H-R diagram, Spectral classification of stars, Saha ionization equation; Virial theorem, gravitational energy, Pre-main sequence evolution, evolution on the main sequence and beyond. Nova and Supernova **6 Lectures**

Nuclear Astrophysics and Beyond: Thermonuclear reactions in stars, pp chains and the solar neutrino problem, the CNO cycle, subsequent thermonuclear reactions, helium burning, nucleosynthesis beyond iron, r and s processes. **2 Lectures**

Stellar structure: Gerenal Relativistic Models: Static spherically symmetric spacetime: physical interpretation of metric terms; energy at infinity, gravitational red shift. Perfect Fluid: Equation of state, equation of motion, TOV equation, stars of uniform density, limit of mass to radius ratio. **6 Lectures**

Newtonian Stars: Hydrostatic equilibrium, equations of stellar structure and evolution; Polytropic equation of state, Lane-Emden equation and its analytic solutions, Homologous stellar models; White Dwarf – electron degeneracy pressure, Chandrasekhar limit; Neutron Stars: formation of neutron stars, TOV equation applied to neutron stars, neutron degeneracy pressure, Maximum mass, schematic structure of neutron stars; Neutron star binaries - high mass, and low mass Neutron star X-ray binaries, Accretion mechanisms, the accretion disc; Pulsars, Quasars, Blazar, Active Galactic Nuclei **12 Lectures**

Black Holes: Formation of black holes (BH), BH binaries, observational evidence; Mathematical theory - BH space-time: conserved quantities, symmetries and Killing vectors, Schwarzschild black hole, event horizon and its nature, infinite red shift, Light cone, removal of coordinate singularity, Eddington-Finkelstein and Kruskal-Szekres coordinates, Penrose diagram. No hair theorem (statement only); Kerr metric in Boyer-Lindquist coordinates, event horizons, Ergosphere, Penrose Process, energy extraction from BH, irreducible mass, dragging of inertial frames; BH Mechanics: Hawking Area Theorem (statement only), surface gravity, four laws of BH thermodynamics, Hawking Radiation; BH evaporation (qualitative discussion) **14 Lectures**

Suggested References:

1. Suggested references for the course General Theory of Relativity – E04
2. An Introduction to the Study of Stellar Structure – S. Chandrasekhar, Dover Publications, 2003
3. Astrophysics – Stars and Galaxies : K.D. Abhyankar, Universities Press, 2001
4. Astrophysics – A. Raychaudhuri, Cambridge University Press
5. An Introduction to Modern Astrophysics – B.W. Caroll, D.A. Ostlie, Cambridge University Press
6. Lectures on Astrophysics – S.W. Weinberg, Cambridge University Press

7. Black Holes, White Dwarfs and Neutron Stars – S.L. Shapiro, S.A. Teukolsky, Wiley-VCH
8. High Energy Astrophysics – M.S. Longair, Cambridge University Press.

Astrophysics & Cosmology Experiments – E07

Elective Course; 90 Hours

1. Basics of astronomical/cosmological data analysis : Chi-square analysis, Bayesian statistics
2. Computation of various derivatives of metric tensor
3. Preparing the H-R diagram for the stars in our Galaxy using data from the Hipparcos satellite.
4. Verification of Hubble-Lemaitre law and determination of the Hubble parameter from it using galaxies from the given data set.
5. Computing the cosmological distances: (i) proper distance, (ii) luminosity distance and (iii) angular diameter distance as a function of redshift in various cosmological models.
6. Measurement of various neutron star parameters using satellite based X-ray data
7. Measurement of various black hole parameters using satellite based X-ray data
8. Determination of limb darkening co-efficient in Solar limb darkening experiment
9. Characterization of charged coupled device
10. Faraday Rotation experiment : A basis to understand dispersion of light through interstellar medium

Some new experiments may be added in phases

1. Classification of stars from their spectra
2. Identification and classification of star-forming galaxies and Active Galactic Nuclei using their emission lines and BPT diagnostic diagram
3. Calculating star formation rates in galaxies using their H-alpha lines
4. Computing stellar mass of galaxies using various stellar synthesis models
5. Measuring rotation curve in galaxies etc.

The analyses will utilize data that are publicly available in various databases.

Suggested References:

1. Suggested references in Cosmology E05 and Astrophysics E06 courses.
2. Practical Statistics for Astronomers – J. V. Wall and C.R. Jenkins, Cambridge University Press
3. User guides of the related astronomical software

Condensed Matter Physics I – E08

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Many Body Techniques: Hartree and Hartree-Fock approximations, correlation energy, second quantization formalism, occupation number representation, canonical transformation, Hartree and Hartree - Fock approximations in second quantized notation, application of Hartree-Fock theory to the free electron exchange energy, first order perturbation theory for an electron gas, broken symmetry and Goldstone modes with spin waves, phonons, magnons. **15 Lectures**

Electron Energy Band Theory: Bloch theorem, Equivalent and nonequivalent wave vectors and star of a wave vector, Empty lattice band, Fermi surface, orthogonalised plane wave (OPW) method, Augmental plane wave method (APW), Green's function (KKR) method, introduction to density functional technique, relativistic energy bands and spin orbit coupling effects, impurity states and the effective Hamiltonian Method. **10 Lectures**

Electrons in Solids: Interacting electron gas, screening, plasma oscillations, Dielectric function of an electric gas ill random phase approximation, limiting cases of Friedel oscillation, strongly interacting Fermi system, elementary introduction to Landau's quasi particle theory of a Fermi liquid, strongly correlated electron gas. **5 Lectures**

Electronic Properties in Magnetic Field: k-space analysis of electron motion in uniform magnetic field, idea of closed, open and external orbits, cyclotron resonance, Azbel-Kaner resonance, energy levels and density states in a magnetic field, thickness quantization in 2-D electron gas. **10 Lectures**

Electronic Transport Properties: The Boltzmann equation and relaxation time, Electrical conductivity, Thermoelectric effect, Thermal conductivity, The Widemann Franz law, Hall effect and magnetoresistance in two band model. **10 Lectures**

Group Theory in Crystalline Solids: Crystalline symmetry operators, crystal point groups, classification of point groups according to crystal systems, symmetry of crystalline potential, splitting of ionic levels by crystalline potential of different symmetries -medium and weak field cases, Crystal space groups and representation of symmetric space groups, derivation of equivalent point positions (with examples from triclinic and monoclinic systems), experimental determination of space group. **10 Lectures**

Suggested Reference:

1. The Wave Mechanics of Electrons in Metals – S. Raimes, North Holland Publishing
2. Many Electron Theory – S. Raimes, North Holland Publishing
3. Many-Particle Physics – G.D. Mahan, Plenum Press
4. Principles of the Theory of Solids – J.M. Ziman, Cambridge University Press
5. Advanced Field Theory in Solid State Physics - J.M. Ziman
6. Quantum Theory of Solid – C. Kittel, Wiley
7. Introduction to Solid State Theory – O. Madelung
8. Solid State Physics – N.W. Ashcroft, N.D. Mermin, Brooks / Cole
9. Theoretical Solid State Physics (Vol. I and II) – A. Haug

Condensed Matter Physics II – E09

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Elastic Properties of Solids: Thermoelasticity in anisotropic solids, third and fourth order elastic constants, Cauchy relation and condition for anisotropy, measurements of elastic constants, theory of elastic constants of crystalline solids. **6 Lectures**

Lattice Dynamics and Optical Properties of Solids: Theory of lattice vibrations in harmonic approximation, phonon-phonon interaction, lattice thermal conductivity of insulators, anharmonicity, thermal expansion, electron-phonon scattering, normal and Umklapp process, interaction of electrons with photons, polaritons, Lyddane-Sachs-Teller relation, one phonon absorption, interaction of electrons with acoustic and optical phonons, polaron and plasmon. **10 Lectures**

Exotic Properties of Solids: Aperiodic solids and quasi crystals, Penrose lattices and their extension to 3-dimensions, special carbon solids, topological insulators, low-dimensional systems. **5 Lectures**

Magnetism in Condensed Matter: Exchange interactions, Landau theory of ferromagnetism, Heisenberg and Ising models, spin glass, magnons, the Kondo effect, superparamagnetism, magnetoresistance, GMR, spin chains, spinons, spin ladders, the Jahn-Teller effect, crystal field theory, spin electronics. **15 Lectures**

Superconductivity: Cooper pairs, BCS ground state from Froehlich electron-phonon Hamiltonian, Bogolibuov-Valantin transformation, energy gap and critical temperature, quantum interference, SQUID, high T_C superconductors. **8 Lectures**

Magnetic Resonance Techniques: Mössbauer effect, electron spin resonance, nuclear magnetic resonance, muon spin rotation. **6 Lectures**

Suggested References:

1. Quantum Theory of Solids – C. Kittel, Wiley
2. Solid State Physics – N.W. Ashcroft, N.D. Mermin, Brooks / Cole
3. Introduction to theory of Solid State Physics – J. Patterson, B.C. Bailey, Springer
4. Introduction to Solid State Theory – O. Madelung, Springer
5. Solid State Physics – D.W. Snoke, Addison-Wesley

Condensed Matter Physics Experiments – E10

Elective Course; 90 Hours

1. Study of electrical conduction in organic semiconductors
2. Study of dielectric property of a given material
3. Study of heat capacity of a given material
4. Study of thermal stability of a given material
5. Study of UV-Vis Spectra of a given material
6. Study of powder diffraction pattern of a given material
7. Study of nature of color centers in a given material.
8. Fabrication of thin film by spin coating technique and it's electrical characterization.
9. Determination of Mössbauer hyperfine parameters.

Some more experiments will be added.

Nuclear Physics I – E11

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Nuclear Radiation Detector: Ionizing radiation: ionization and transport phenomena in gases, avalanche multiplication; detector properties: detection, energy measurement, position measurement, time measurement; Gas Counters: ionization chambers, proportional counters, multi-wire proportional counters (MWPC), Geiger-Muller counters; Solid State Detectors: semiconductor detectors, integrating solid state devices, surface-barrier detectors, strip detectors; Scintillation Counters: organic and inorganic scintillators, theory, characteristics and detection efficiency; basic principle and working of neutron detectors. **15 Lectures**

Nuclear Electronics and Signal Processing: Analog and digital pulses - Pulse shaping - Linear amplifiers - Pulse height discriminators - Single channel analyzer (SCA) - Multi-channel analyzer (MCA); NIM/CAMAC/VME data acquisition system, NIM, ECL and TTL standard, types of noise; coincidence technique (slow and fast); digital signal processing. **10 Lectures**

Accelerators: Different types of accelerators - layout and components of accelerators; Linear Accelerators: Fundamental properties of accelerating structure - particle acceleration by EM waves - Longitudinal particle dynamics in Linac - transverse beam dynamics in a Linac: Basic principle and design of accelerators viz electrostatic, electrodynamics, resonant with special emphasis on Pelletron and Cyclotron; accelerator facilities; beam optics (brief overview only); vacuum techniques; target preparation; production of radioactive ion-beam; synthesis of super-heavy elements. **10 Lectures**

Nuclear Techniques and Applications: Methods for charge and mass identification: ΔE-E; energy loss, Time of Flight (TOF), mass spectrometer, neutron: TOF and n-γ discrimination, Detector array (γ-rays, neutrons, charged particles), multiplicity, charged particle, neutron and γ-ray spectroscopy, angular distribution and correlation; brief ideas of multipolarity and transition probabilities, Weisskoff-estimate, internal conversion coefficient and their ratios, polarization and its measurement, Doppler shift and Doppler broadening, Methods for life time measurements: delay coincidence, pulse beam (slope and centroid shift), recoil distance and Doppler shift attenuation; measurement of magnetic and quadrupole moment (g-factor, Hyperfine interaction); application of nuclear techniques in other areas. **15 Lectures**

Suggested Reference:

1. Radiation Detection and Measurement – G.F. Knoll, John Wiley & Sons
2. Techniques for Nuclear & Particle Physics Experiments – W.R. Leo, Springer & Verlag
3. Physics & Engineering of Radiation Detection – S.N. Ahmed, Academic Press
4. Nuclear Physics, Principles and Applications – J.S. Lilly, John Wiley & Sons

Nuclear Physics II – E12

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Nuclear Force: Few-nucleon systems, Electromagnetic properties of the deuteron and the Rarita-Schwinger equation; theory of scattering, nucleon-nucleon scattering, polarization in nucleon-nucleon scattering, scattering length, probing charge distribution with electrons, Form factors. **10 Lectures**

Nuclear Structure: Shell model: review of Shell Model, magic numbers, single-particle shell model; seniority scheme, M and J-scheme; concept of pairing force - gap equation and ground state properties, idea of quasiparticles; Collective Model of nucleus: deformable liquid drop and nuclear fission, shell effects on liquid drop energy, collective vibrations and rotations, pattern of excited states; single particle in deformed potential: Nilsson Model and Nilsson Diagram; Particle Rotor Model, deformation alignment and rotational alignment; High Spin Nuclear Structure Phenomena, Gamma Spectroscopy, Triaxiliaty, Different types of Nuclear Isomers. **20 Lectures**

Nuclear Reactions: Different types of reactions, Discussion and theory of direct reactions, Plane wave analysis of scattering and reaction cross-section, Coupled channels, Distorted Wave Born Approximation (DWBA), Optical Model, Derivation and discussion of Breit-Wigner formula for scattering and reaction - concept of resonance, statistical theory of nuclear reaction – Concept of level density parameter; Pre-equilibrium reactions, Spectroscopic factor and determination of nuclear level properties, Theory of Nuclear fission dynamics (a brief outline) **15 Lectures**

Nuclear Reactors: Different kinds and their operation principles, overview of different types of reactors in India, energy generation using reactors, diffusion of thermal neutrons, critical size of a reactor – determination of the critical size under different configurations **5 Lectures**

Suggested References:

1. Introductory Nuclear Physics – Kenneth S. Krane, John Wiley & Sons
2. Basic Ideas and Concepts in Nuclear Physics – K. Heyde, Overseas Press
3. Nuclear Structure from a Simple Perspective – Richard F. Casten, Oxford University Press
4. Nuclear Models – W. Greiner and J.A. Maruhn, Springer
5. Introduction to Nuclear Reactions – G.R. Satchler, Springer
6. Nuclear Physics: Theory and Experiment – R.R. Roy, B.P. Nigam, New Age International Publishers

Nuclear Physics Experiments – E13

Elective Course; 90 Hours

1. Study of energy resolution characteristics of a Gamma ray spectrometer by digital signal processing (DSP).
2. Study of statistics of nuclear counting of a GM counter.
3. Study of beta-decay to determine mass absorption coefficient of Al and efficiency of a GM counter.
4. Linear and mass attenuation coefficient for gamma rays and estimation of efficiency of GM counter.
5. To study the gamma ray spectra of different radioactive nuclei with a NaI (Tl) scintillator using SCA.

List of experiments to be introduced in phase:

1. Study of Compton scattering with a NaI(Tl) scintillator.
2. Coincidence measurement of gamma rays using fast liquid scintillator.
3. To study energy characteristics of beta rays and evaluation of end-point energy using beta spectrometer.
4. To study Rutherford scattering using alpha spectrometer.

Particle Physics I – E14

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Relativistic Kinematics: System of units; Lorentz Transformation, rapidity and pseudorapidity, kinematics of two-body and three-body decays; threshold energy for a process, invariant quantities relevant for collisions and decays; Mandelstam variables; laboratory and centre-of-mass frame; phase space. **6 Lectures**

Experimental Techniques:
Accelerators and beams - linear and cyclic accelerators; fixed-target and colliding beam experiments; neutral and unstable particle beams, neutrino beams.
Particle Detection Energy loss of particles in matter, Bethe-Boch formula – ionization, radiation, nuclear interaction, pair production; ranges and interaction lengths; gas detectors, semiconductor detectors, scintillation counters, Cerenkov counters; Electromagnetic and hadronic showers, calorimetry; Some modern detector systems – CDF, CMS, Belle **8 Lectures**

Fermionic wave functions: Properties of Dirac spinors – spin, helicity, Lorentz Transformation, charge conjugation and parity operators; properties of gamma matrices; bilinear covariants and their properties under transformations. **6 Lectures**

Electromagnetic interactions: scattering amplitudes, Trace theorems; scatterings – electron-muon, Compton, electron-positron; differential and total cross-sections **10 Lectures**

Weak Interaction: Different weak decays of quarks, leptons and hadrons; quark mixing – Cabibbo angle, CKM matrix, comparison of decay rates; charged current interaction, V-A theory, decay of muon and charged pion, neutron; neutral current interaction; lepton universality from experimental data. **10 Lectures**

Neutrinos: Neutrinos from different sources - their energy spectrum, detection techniques; Neutrino experiments - Homestake, SuperKamiokande, K2K, Dune, IceCube; comparison of results from different experiments – solar neutrino problem, neutrino oscillation; neutrino masses and mixing; Dirac and Majorana neutrinos; double beta decay, neutrinoless double beta decay – experimental status and implications. **10 Lectures**

Suggested References::

1. Introduction to Elementary Particles - D.J. Griffiths, Wiley-VCH.
2. Quarks and Leptons – F. Halzen and A.D. Martin, Wiley-VCH
3. Introduction to High Energy Physics – D.H. Perkins, Cambridge University Press
4. Particle Physics – B.R. Martin and G. Shaw, John Wiley and Sons
5. An Introductory Course of Particle Physics – P.B. Pal, CRC Press
6. Modern Elementary Particle Physics – G. Kane, Addison-Wesley
7. The Review of Particle Physics, Particle Data Group, http://pdg.lbl.gov

Particle Physics II – E15
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Basic Concepts: Elementary particles, their interactions, conservation of quantum numbers, allowed and suppressed processes; discovery of quarks and leptons; concept of color; outline of the Standard Model. **6 Lectures**

Symmetries: Discrete Symmetries – Parity (P), Charge-Conjugation (C), Time-Reversal, CP-symmetry, mixing in neutral Kaons; CPT-Theorem; Lie-groups, Lie-algebra, Lorentz group; SU(2), SU(3) and SU(N) groups. **10 Lectures**

Quark Model: Baryon and meson multiplets; Baryon and meson masses, Gell-Mann-Okubo mass formula; Heavy quark multiplets; concept of colour **4 Lectures**

Bound states – Positronium, Quarkonium, Charmonium, Bottomonium, Light Quark Mesons; Baryons - Baryon Wave Functions, Colour, Magnetic Moments, Masses **5 Lectures**

Quantaum Chromodynamics: electron-proton scattering; structure of baryons **5 Lectures**

Gauge Theory: Gauge invariance - Abelian, non-Abelian, higher order diagrams and evolution of gauge couplings (concept only). **5 Lectures**

Standard Model (SM): Spontaneous symmetry breaking, Higgs mechanism, SM of Electroweak interaction, Spontaneous Breaking of SU(2)×U(1) symmetry; determination of W, Z and Higgs masses, Fermion mass generation and mixing; CP violation and the necessity of the third generation, Grand Unified Theory, neutrino oscillations. **10 Lectures**

Beyond the Standard Model (BSM): Shortcomings of the SM, Supersymmetry (SUSY) - basic ideas, particle content of SUSY, R-Parity, implications of R-Parity conservation and non-conservation, Dark Matter; other BSM ideas. **5 Lectures**

Suggested References:

1. Introduction to Elementary Particles – D.J. Griffiths, Wiley-VCH
2. Quarks and Leptons – F. Halzen and A.D. Martin, Wiley-VCH
3. Introduction to High Energy Physics – D.H. Perkins, Cambridge University Pres
4. Particle Physics – B.R. Martin and G. Shaw, John Wiley & Sons
5. An Introductory Course of Particle Physics – P.B. Pal, CRC Press
6. Modern Elementary Particle Physics – G. Kane, Addison-Wesley Publishing Company
7. The Review of Particle Physics, Particle Data Group, http://pdg.lbl.gov

Plasma Physics – E16

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Introduction to Plasma: Plasma as an ionized gas, quasi-neutrality, collective behaviour of plasma particles, Debye shielding, plasma frequency, characteristic length and time scales of a plasma, collision frequency; plasma sources: Laboratory sources of plasma, Natural sources of plasma, Van Allen radiation belts, the ionosphere, the sun and its atmosphere, plasma beyond solar system; Theoretical description: single particle motion in prescribed electric and magnetic fields, fluid description, statistical mechanical description. **6 Lectures**

Single Particle Motion: motion of charged particles in a constant uniform magnetic and electric fields, magnetic moment of a gyrating charged particle, concept of guiding centre, drift velocities of the guiding centre in combined electric and magnetic fields, gravitational field, currents associated with drift velocities; particle motion in a constant but spatially non-uniform magnetic field, average force acting on a charged particle in a non-uniform magnetic field, Adiabataic invariants, magnetic mirror effect, confinement of plasma in a mirror configuration, loss cone, Fermi acceleration, Gradient and curvature drifts, confinement in earth's magnetic fields; Particle motion in slowly time-varying electric fields, polarization drift and current, plasma as a dielectric medium; slowly time-varying magnetic field and space varying electric field, adiabatic invariant and magnetic heating of plasma. **8 Lectures**

Description of Plasma as a Fluid:
Fluid models of plasma: Equation of continuity, momentum equation, cold & warm plasma models, concept of pressure tensor, equation of state, fluid drifts and diamagnetic current.
Magnetohydrodynamics: MHD equations, generalized Ohm's law, induction equation, magnetic Reynolds number, diffusion of magnetic field lines in a resistive plasma, "Frozen-in" magnetic fields, MHD equilibria, force-free magnetic fields, Hydromagnetic waves - Alfven and magnetosonic waves.
Plasma confinement in magnetic fields: Pinch effect, theta pinch, Z-pinch, Bennett relation for Z-pinch, general screw pinch, safety factor. **10 Lectures**

Waves in a Two-Fluid Plasma: Parallel and perpendicular propagating waves, longitudinal and transverse waves, electrostatic and electromagnetic waves; Unmagnetized Plasma – electron plasma oscillations, Langmuir waves, ion acoustic and ion plasma waves, two stream instability, electromagnetic waves in an unmagnetized plasma; waves in a magnetized plasma – right and left circularly polarized waves, Ordinary (O) and Extraordinary (X) waves, Whistlers, Helicons and Faraday rotation. **10 Lectures**

Collisions and Diffusion in Weakly Ionized Plasmas: Ambipolar diffusion, Fick's law, diffusion across magnetic fields. **4 Lectures**

Plasma Kinetic Theory: Distribution function, its evolution in phase space - Boltzmann and Vlasov equations, Physical picture of Landau damping. **6 Lectures**

Experimental Techniques: Plasma in a discharge tube, Langmuir probe, Measurement of density and temperature, Microwave measurements, Basic idea of laser induced fluorescence technique. **6 Lectures**

Suggested References:

1. Introduction to Plasma Physics and Controlled Fusion – F.F. Chen, Springer
2. Fundamentals of Plasma Physics – J.A. Bittencourt, Springer
3. Principles of Plasma Physics – N.A. Krall, A.W. Trivelpiece, San Francisco Press

Laser Physics – E17
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Introduction: Einstein coefficients, Light amplification, Threshold condition, Line broadening mechanism, Ammonia beam maser, MASER operation. **4 Lectures**

Coherent states: Minimum uncertainty wave-function, temporal development of minimum uncertainty wave-function, coherent state of the radiation field, properties of coherent states. **4 Lectures**

Semiclassical Theory of Laser: Electromagnetic field equations, expansion in normal modes of cavity, Lamb's self consistency equations, Density matrix equations, Polarization of the medium, Single mode operation. **5 Lectures**

Gas Laser Theory: Polarization of Doppler broadened medium, Rate equations and solutions, Hole burning, Lamb dip, two-mode operation. **4 Lectures**

Multimode Operation: Polarization of the media, free-running operation, locking of beat frequencies between N-modes, Two-mode operation. **4 Lectures**

Quantum theory of laser: Quantization of the radiation field, Photon number states, Field equation of motion, Laser photon statistics, Laser line width. **6 Lectures**

Properties of laser beams and types of lasers: Coherence properties of laser light, Spatial and temporal coherence, Directionality; different types of lasers - Ruby Laser, Helium-Neon Laser, Carbon di-oxide Laser, Solid state Laser, Semiconductor diode Laser, Quantum well lasers, Free electron Lasers, and Dye Lasers. **10 Lectures**

Applications of lasers in Science and Industry:
(a) Spatial frequency filtering, Holography, Three dimensional hologram, Reconstruction.
(b) Laser induced fusion, laser energy requirements, energy confinement, Isotope separation.
(c) Harmonic generation, Stimulated Raman emission, self focusing.
(d) Lasers in industries: Material processing, tracking, LIDAR, medical application **8 Lectures**

Suggested References:

1. The quantum Theory of Light – R. Loudon (Oxford Science publication)
2. Lasers: Theory and Applications – K. Thyagrajan and A.K. Ghatak (Plenum Press)
3. Laser Physics – M. Sargent III, M.O. Scully and W.E. Lamb Jr. (Addition Wesley)
4. Introduction to Laser Physics – K. Shimoda (Springer)

Physics of Dense Matter – E18
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Relatively Low Density Region: Hartree and Hartree-Fock Equations – use of variational method; application to bulk nuclear matter, finite nuclei; Thomas-Fermi, Thomas-Fermi-Dirac equations; Thermal Thomas-Fermi and Thermal Hartree-Fock equations. **10 Lectures**

Matter of Moderate Density-I: Nuclear Skyrme interaction; direct and exchange interactions; Nuclear symmetry energy; Nuclear compressibility; Harrison-Wheeler (HW), Baym-Pethick-Sutherland (BPS) and Baym-Bethe-Pethick (BBP) equation of states; nuclear Coulomb and lattice energies. **15 Lectures**

Matter of Moderate Density-II: Nucleon-Nucleon scattering and nuclear realistic potential; Lipmann-Schwinger equation, Reid soft and hard core potentials, Brueckner-Bethe-Goldstone equation. **10 Lectures**

Matter at High and Ultra-High Density: Dirac equation and relativistic Hartree and Hartree-Fock equations with some application to bulk nuclear matter and finite nuclei; Mean field theory for nuclear matter with sigma-omega-rho meson exchange; hyperons in dense nuclear matter; pion-nucleon interaction and the possibility of pion condensation; quark matter: quark-hadron phase transition at high density; Study of dense quark matter; with relativistic Hartree-Fock equation and relativistic version of Landau theory of Fermi liquid at zero temperature. **10 Lectures**

Suggested References:

1. Physics of Dense Matter – Y.S. Leung, World Scientific.
2. Black Holes, White Dwarfs and Neutron Stars – S.L. Shapiro and S.A. Teukolsky, John Wiley & Sons.
3. Compact Stars: Nuclear Physics, Particle Physics and Gravitation – N.K. Glendenning, Springer.

Quantum Electronics I – E19

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Review of Quantum Mechanics: Time dependent perturbation theory; Broadening of spectral line; Density matrix; Liouville's equations of motion; Reduced density matrix; Master equation.
5 Lectures

Element of Field Quantization: Lattice vibrations and their quantization, Concept of acoustic and optical branches; Thermal excitation of lattice modes; Normal mode expansion of E.M field in a resonator; Quantization of the radiation field; Coherent State; Bunching and Anti bunching of photons in a radiation field, Hanbury-Brown-Twiss experiment. **8 Lectures**

Atom-Field Interaction: Introduction, Density Matrix approach to atomic susceptibility, significance of nonlinear susceptibilities; Spontaneous and induced transitions - Einstien's treatment, homogeneous and inhomogeneous broadening of spectral line; Hole burning, Lamb dip. **7 Lectures**

Coherent Interaction of Atom With E.M. Field: Introduction, Vector representation; Optical Bloch equation; Optical Nutations; Superradiance; photon echoes and self induced transparency. **8 Lectures**

Lasers: Optical resonators, lossless optical resonators, laser oscillation; gas Lasers; Semiconductor diode lasers and free electron lasers; Q-Switching and mode locking of lasers.
7 Lectures

Quantum Information Processing: Basic principle of Quantum Cryptography, Quantum key distribution -BB84 protocol, Error corrections and identity verifications, Single photon sources, Practical demonstration of Quantum Cryptography. **5 Lectures**

Quantum Computing: Quantum Bits, Quantum logic gates and circuits, Decoherence and error corrections, Applications of Quantum computers: Deutsch's algorithm, Grovers algorithm and Shors' algorithm, Experimental implementation of quantum computers. **5 Lectures**

Entangled States and Quantum Teleportation: Entangled states, Generation of entangled photon pairs, Bells' inequality and experimental verification of Bells' theorem, Principles of teleportation and experimental implementation. **5 Lectures**

Suggested References:

1. Quantum Electrics – Amnon Yariv (John Wiley and Sons)
2. Nonlinear Optics: Basic Concepts – D.L. Mills (Springer)
3. Introductory Quantum Optics; Christopher C. Gerry and Peter L. Knight (Cambridge)
4. Nonlinear Optics – E.G. Sauter (Wiley-Interscience)
5. Quantum Statistical Properties of Radiation – William H. Louisell (Wiley Classics Library)
6. Quantum Optics: An introduction – Mark S. Fox (Oxford Master Series in Physics)

Quantum Electronics II – E20

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Topics in Nonlinear Optics: Nonlinear EM field Hamiltonian; Basic concept of nonlinearities; Nonlinear optical susceptibility tensor; Second Harmonic generations; Basic concepts of Parametric amplification; Parametric oscillation; quantum mechanical treatment; Frequency up conversion. Concept of self focusing of the optical beams; Stimulated Raman and Stimulated Brillouin Scattering. **17 Lectures**

Phase conjugate optics: Propagation through a distorting medium, Image transmission in fibers, Theory of phase conjugation by four wave mixing, Optical resonators with phase conjugate reflectors, ABCD formalism and practical applications. **8 Lectures**

Recent Developments in Quantum Optical Experiments: Generation of Squeezed states; Inversionless lasers; optical molasses; Atomic Fountain; Bose-Einstein condensate. **10 Lectures**

Guided Wave Optics: Wave guide modes, planer and periodic waveguides, directional coupling, supermodes, propagation in optical fiber. Nonlinear Schrodinger equation; pulse propagation in a dispersive medium, soliton, gap soliton. **15 Lectures**

Suggested References:

1. Quantum Electrics – Amnon Yariv (John Wiley and Sons)
2. Nonlinear Optics: Basic Concepts – D.L. Mills (Springer)
3. Nonlinear Optics – E.G. Sauter (Wiley-Interscience)
4. Quantum Statistical Properties of Radiation, William H. Louisell, Wiley Classics Library
5. Quantum Optics: An introduction – Mark S. Fox, Oxford Master Series in Physics)
6. Quantum Statistical Properties of Radiation, W. Louisell,

Quantum Electronics Experiments – E21

Elective Course, 90 Hours

1. To fabricate a precision current controller for a diode laser and study its stability.
2. To study the diode laser drive current versus output power of a laser diode and hence to determine the threshold current for lasing at different working temperature and hence to quantify the dependence of threshold current over working temperature.
3. To fabricate a DC power supply (± 12 volt/± 15 volt) and a photodetector and hence to determine the optical power to voltage conversion ratio of the detector.
4. To determine the temperature tuning rate of a laser diode by using a Fabry-Perot etalon as the frequency marker.
5. To determine the current tuning rate of a laser diode by using a Fabry-Perot etalon as the frequency marker.
6. To study and characterize the intensity profile of a laser beam.
7. To study the saturation absorption line shape of alkali atoms (Rb or Cs) by Lamb dip spectroscopy and hence to determine the separation between the hyperfine peaks.
8. To study the absorption line shape of molecular sample (water vapour/ oxygen/ acetylene) by using a tunable laser source.
9. To study the transmission of laser beam through optical fiber and figure out the loss due to (i) bending of fiber, (ii) polarization of the coupled beam, (iii) length of the fiber.
10. To determine the saturation intensity of an absorbing sample (preferably Rb/Cs) from the absorption line shape.

Suggested References:

1. A simple scanning semiconductor diode laser source and its application in wavelength modulation spectroscopy around 825 nm, A. Ray, A. Bandyopadhyay, S. De, B. Ray, P.N. Ghosh, Optics & Laser Technology, Volume 39, Issue 2, March 2007, https://doi.org/10.1016/j.optlastec.2005.07.00
1. Using diode Lasers for Atomic Physics, C.E. Wieman, L. Hollberg, Review of Scientific Instruments **62**, 1 (1991); https://doi.org/10.1063/1.1142305
2. Laser Spectroscopy 1, Wolfgang Demtrodr, Springer Verlag.

Communications - E22

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Microwave signal Generation and Amplification: Klystron- Theory of amplification, velocity modulation, electron bunching, catcher current expression, optimum buncher catcher separation, efficiency; Reflex Klystron - theory of oscillation, condition of oscillation, physical mechanism, output power; Travelling Wave Tube - Theory of microwave amplification, electron bunching, slow wave structure, wave propagation on the helix, amplifier gain calculation; Magnetron - basic concept, mechanism of oscillation, beam field interaction, cut-off magnetic field, cut-off anode voltage. **10 Lectures**

Antenna: Radiation from elementary dipole, half-wave dipole radiation, radiation resistance, linear array of antennas - broad side array, end fire array, principal lobe width calculation, Dish antenna, Cassegrain feeding. **7 Lectures**

Optical Signal Generation and Detection: Laser diode - mechanism of lasing, concept of feedback, optical and carrier confinement; photodiodes (PD) - pn junction PD, PIN PD, APD, UTC PD. **5 Lectures**

Optical Transmission of Signals: Principle of optical transmission in fiber- numerical aperture-cut-off, single mode and multimode fibers, Fiber loss, fiber dispersion. **4 Lectures**

Noise in Communication Systems: Analyses of noise in DSB+C, DSB-SC, SSB-SC receiving systems- figure of merit- Envelope detection and synchronous detection noise performance-Noise in FM receiver - Concept of threshold - Pre-emphasis and de-emphasis. **7 Lectures**

Digital modulation:
Review of ASK, FSK, PSK, DPSK, QPSK signals- PCM signal generation; Sampling - Sampling theorem, PAM, quantizing-encoding- delta modulation. Multilexed communication- Time division multiplexing, Frequency division multiplexing. Mobile communication. **7 Lectures**

Optical communication: IM-DD fiber optic link, direct modulation - external modulation, modulation distortion, bandwidth, wavelength division multiplexing (WDM), dense WDM, Ultra-dense WDM communication. **4 Lectures**

Television: Sound and picture transmission, scanning, video bandwidth calculation, synchronizing and blanking pulses, VSB modulation, CCIR-B system, Introduction of colour TV. **6 Lectures**

Suggested References:

1. Microwave Devices and Circutes – S.Y. Liao, Pearson
2. Antenna Theory and Design (Revised Edition) – R.S. Elliott, John Wiley & Sons
3. Integrated Optics Theory and Technology – R. Hunsperger, Springer
4. Communication Systems – B.P. Lathi, BS Publicatios
5. Television and Video Engineering - A.M. Dhake, Tata-McGraw-Hill
6. Advanced Electronics – T. Chattopadhyay, CBS Publishers & Distributors

Digital Integrated Circuits and Microprocessors – E23

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

IC Fabrication Technology: Types of semiconductor materials, silicon wafer preparation, process steps for IC Technology - cleaning, oxidation, diffusion, ion implantation, lithography, etching metalization, MOSFET fabrication process; Fabrication of monolithic IC, VLSI design - design rules, stick diagram, chip assembly and packaging techniques, CMOS fabrications. **7 Lectures**

Discrete and integrated digital circuits:
Digital Logic family - DTL, TTL, ECL, CMOS.
Digital IC-Multiplexer, demultiplexer, encoder, decoder, arithmetic circuits, ALU, registers, Counters, A/D converter and D/A converter, multivibrator and Timer.
Memories - Digital MOS circuits NMOS and CMOS gates (AND, NAND and NOT), Dynamic MOS circuits, MOS shift register, ROM, RAM, PROM, EPROM, static (SRAM) and dynamic (DRAM) random access memories, Charge Csoupled Device **18 Lectures**

Microprocessors and Microcontrollers: Architecture of 8085, instruction cycle, machine cycle, timing diagram; basic interfacing concepts- memory and I/O interfacing, types of instruction, addressing modes; Assembly Language Programming: looping, counting and indexing-counters and timing delays; stack and subroutine; interrupts and DMA, programmable peripheral ICs 8255A, 8251A, 8279, 8253, 8237, 8259, A/D and D/A converters and interfacing of the same; Serial and parallel data transfer; 8086 microprocessor - architecture and programming; 8051 microprocessor - Architecture and its applications; other advance microcontroller; Data Acquisition System (DAS) **25 Lectures**

Suggested References:

1. Digital Fundamentals – T.L. Flloyd, Pearson Education
2. Digital Principles and Applications – A.P. Malvino, D.P. Leach, McGraw-Hill
3. Microprocessor Architecture, Programming and Applications with 8085/8085A – R.S. Gaonkar, Prentice Hall
4. Introduction to Microprocessors – A.P. Mathur, Tata McGraw-Hill
5. VLSI - Design Techniques for Analog and Digital Circuits – R.L. Geiger, P.A. Allen, N.R. Strader

Electronics Experiments – E24

Elective Course; 90 Hours

1. Design a logarithmic amplifier using (a) diode and (b) matched pair of transistors. Calculate numerical constant η at room temperature from input voltage vs. output voltage curve.
2. Design an antilogarithmic amplifier by using matched pair of transistors and draw input voltage vs. log of output voltage curve.
3. Design a regulated power supply without current limiter and with current limiter using (a) transistor as comparator and (b) op-amp as comparator. Draw the regulation characteristics and find-out the output resistance, percentage of regulation and ripple factor before and after regulation.
4. Set up a microwave AM generation and detection experiment. Measure microwave AM index as a function of microwave modulating signal voltage. Measure detected voltage as a function of microwave modulating signal voltage.
5. Design a PLL circuit using IC 565 and study the variation of VCO frequency with time constant (RC). Examine phase locking behavior of the circuit. Measures lock range and capture range of the PLL. Study the FM demodulation performance.
6. Design a two-bit parallel adder using only NAND gates which is equivalent to IC 7482. Design a BCD adder using 4-bit parallel adder (IC 7483).
7. Design a presetable program counter using flip flops and basic logic gates.
8. Design universal shift resister using flip flops and basic logic gates. Use IC 7495 shift resister and design shift/ring counter.
9. Programming in Microprocessor 8085: block transfer, sorting, arithmetic operation. Interfacing of 8085 with peripheral kits.
10. 10. Design and simulation of electronic circuits.
11. Study of response of optical transreceiver

(All experiments??)

Suggested References:

1. Introduction to digital Principles - Malvino and Leach
2. Microprocessor Architecture, Programming and Applications with 8085/8085A – R.S. Gaonkar, Prentice Hall
3. Integrated Optics: Theory and Technology – R.G. Hunsperger, Springer

Nonlinear Dynamics I – E25
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Linear Systems: Simple Harmonic oscillators (SHO) – free, damped, damped & driven; SHO with time-dependent frequency; Lorentz force; Velocity independent non-conservative linear force; Chain of coupled harmonic oscillators.; Superposition of solutions; Role of initial and boundary conditions. **5 Lectures**

Nonlinear Systems: Introduction & overview; Classifications; Different types of dissipative & non-dissipative nonlinear oscillators; Toda lattice, Calogero-Moser-Sutherland systems, Non-linear Schrödinger equation; sine-Gordon equation; Discrete Systems; Logistic map. **6 Lectures**

Stability Analysis: One and two dimensional flows; Phase portraits on plane; Equilibrium points and linear stability analysis; Classification of equilibrium points; Limit cycles; Poincaré-Bendixon's theorem; Higher dimensional systems; Poincaré section; Hamiltonian Systems; Nonlinear stability analysis; Lyapunov function. **15 Lectures**

Bifurcation: Introduction; Saddle-node, transcritical, pitchfork and Hopf bifurcations; Imperfect bifurcations and catastrophes; Examples: Hysteresis in the driven pendulum; Landau theory of Phase transitions; Josephson junction. **12 Lectures**

Chaos: Introduction; Sensitivity to the initial condition; Different types of attractors; Different routes to chaos; Poincaré map; Chaos in Logistic map, Lorenz system, Damped driven pendulum. **12 Lectures**

Suggested References:

1. Nonlinear Dynamics and Chaos with applications to Physics, Biology, Chemistry and Engineering – S.H. Strogatz, Indian Edition by Sarat Book House, Kolkata.
2. Differential Equations, Dynamical Systems and Introduction to Chaos – M.W. Hirsch, S. Smale, R.L. Devaney, Third Edition, Academic Press.
3. Chaos and Integrability in Nonlinear Dynamics: An introduction – M. Tabor, John Wiley & Sons.
4. Nonlinear Dynamics: Integrability, Chaos and Patterns – M. Lakshmanan, S. Rajasekar, Springer

Nonlinear Dynamics II – E26
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Integrable Systems: Hamiltonian System; Geometric approach to Hamiltonian dynamics; Canonical transformation; Hamilton-Jacobi-Theory; Action-angle variables; Conserved quantities, Integrability, Liouville theorem, Lax pair formulation, Inverse-scattering method; Examples: Cubic Nonlinear Oscillator; Toda Chain; Calogero-Moser-Sutherland systems, Non-linear Schrödinger equation. **15 Lectures**

Approximate Methods: Naive perturbation theory and its failure; Poincaré-Lindstedt Method; Multiple time-scale method; Averaging and Harmonic balance methods; Canonical perturbation theory for Hamiltonian systems; Relaxation oscillation, Parametric oscillator; Examples: Different types of nonlinear oscillators. **15 Lectures**

Chaos: Introduction; Chaos in Hamiltonian Systems; Examples of chaos – Hénon-Heiles system; Toda lattice, Periodically driven undamped Duffing oscillator; Invariant tori; KAM theorem; Lyapunov exponent; Power spectrum, Time-series analysis, Auto-correlation functions; Linear & non-linear electronic circuits & chaos; Applications of chaos. **15 Lectures**

Advanced Topics (Qualitative Discussions Only): Quantum Integrable systems; Quantum chaos; Fractals; Ergodic theory; Synchronization; Pattern formation; Topics suggested by Instructor/ Students. **5 Lectures**

Suggested References:

1. Nonlinear Dynamics and Chaos with applications to Physics, Biology, Chemistry and Engineering – S.H. Strogatz, Indian Edition by Sarat Book House, Kolkata
2. Differential Equations, Dynamical Systems and Introduction to Chaos – M.W. Hirsch, S. Smale, R.L. Devaney, Third Edition, Academic Press.
3. Chaos and integrability in nonlinear dynamics: An introduction – M. Tabor, John Wiley & Sons.
4. Introduction to Perturbation Techniques – A.H. Nayfeh, John Wiley and Sons
5. Nonlinear Dynamics: Integrability, Chaos and Patterns – M. Lakshmanan, S. Rajasekar, Springer
6. Integrable Models – A. Das, World-Scientific

Computational Nonlinear Dynamics – E27

Elective Course; 90 Hours

Review: Numerical Error Analysis; Finding roots of algebraic equations; Diagonalization of matrices; Integration & Solutions of coupled Differential Equations; Examples: Duffing oscillator-undamped, damped & driven; Coupled chain of nonlinear oscillators with cubic nonlinearity and nearest-neighbor interaction.

Basics: Different types of flow diagrams in one and two dimensions ; Attractors; Limit Cycles.

Bifurcation: Different types of bifurcation diagrams in continuous and discrete systems.

Maps: Logistic map; Poincaré map; Henon map

Chaos: Sensitivity to the initial conditions; Different types of attractors; Lyapunov exponent; Time-series analysis; Power spectrum; Auto-correlation functions; Fractals.

Suggested References:

1. Standard resources on C++, Mathematica, Matlab & Python
2. Nonlinear Dynamics and Chaos with applications to Physics, Biology, Chemistry and Engineering – S.H. Strogatz, Indian Edition by Sarat Book House, Kolkata.

NanoScience and NanoTechnology – E28

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Nanoscale Systems: Length scales in physics, Nanostructures: 1D, 2D and 3D nanostructures (nanodots, thin films, nanowires, nanorods), Band structure and density of states of materials at nanoscale, Size Effects in nano systems, Quantum confinement: Energy states on infinite potential well, potential step, potential box, quantum confinement of carriers in 3D, 2D, 1D nanostructures and its consequences. **7 Lectures**

Essential Approaches and Forces at Nanoscale:
Bonding Forces and Energies- Types of bonding- Ionic- Covalent- Metallic - van der Waals-π-π-stacking - Hydrogen bonding. Aggregation of Nanoparticles - Homogeneous aggregation, Heterogeneous aggregation, Coalescence and Rippening; Sedimentation - Dispersion and transformation. Homogeneous Nucleation, Hydrophobic Interactions- Steric Forces. **6 Lectures**

Features of Growth at Nanoscale
Specific Features of Nanoscale Growth - Introduction - Thermodynamics of Phase Transitions, Thermodynamics of Nucleation - Growth – Size Control - Triggering the Phase Transition - Controlling Nucleation – Controlling Growth - Controlling Aggregation-Stability of Colloidal Dispersions. Formation of Metastable Phases- Stability of Small Objects **7 Lectures**

Synthesis of Nanostructure Materials
Physical Methods: Inert gas condensation, Arc discharge, RF-plasma, Plasma arc technique, Ion sputtering, Laser ablation, Laser pyrolysis, Ball Milling, electrodeposition. Microwave synthesis of NPs
Chemical Methods: Metal nanocrystals by reduction, Solvothermal synthesis, Photochemical synthesis, Nanocrystals of semiconductors and other materials by arrested precipitation, Thermolysis routes, Sonochemical routes, Liquid-liquid interface, Hybrid methods, Solvated metal atom dispersion, Solgel, Micelles and microemulsions, Cluster compounds.
Biological Methods: Use of bacteria, fungi, Actinomycetes for nanoparticle synthesis, Synthesis process and application. Electro-spinning Synthesis of Nanofibres, Microfluidic Synthesis of NPs, Green Synthesis of NPs. **12 Lectures**

Characterization Techniques for Nanomaterials: X-Ray Diffraction, Optical Microscopy, Scanning Electron Microscopy, Transmission Electron Microscopy, Ultraviolet-Visible-Infrared, Fourier Transform Infrared Spectroscopy, Raman spectroscopy, Photoluminescence, Fluorescence, Phosphorescence, Electroluminescence, Photoconductivity, Energy Dispersive X-ray spectroscopy, Differential Scanning Calorimetry (DSC) – Thermo-gravimetric analysis (TGA), Resistivity, Polarization, Dielectric properties, Magneto-Resistance, Vibrating Sample Magnetometer, Superconducting Quantum Interference Device, Magneto-optical Kerr Effect. **11 Lectures**

APPLICATIONS: Applications of nanoparticles, quantum dots, nanowires and thin films for photonic devices (LED, solar cells). CNT based transistors. Optical switching and optical data storage. Magnetic data storage. graphene, graphene oxide and its utility in making energy devices. **7 Lectures**

Suggested References:

1. Introduction to Nanotechnology – C.P. Poole, Jr. F.J. Owens, John Wiley & Sons.
2. Nanotechnology: Principles & Practices – S.K. Kulkarni, Springer.
3. Springer Handbook of Nanotechnology – Bharat Bhushan, Springer (2010).
4. The Power of Click Chemistry for Molecular Machines and Surface Patterning – J.M. Spruell, Springer (2016).
5. Semiconductor Nanowires: Materials, Synthesis, Characterization and Applications – J. Arbiol, Q. Xiong, Woodhead Publishing (ELSEVIER Group).
6. Introduction to Nanoscience - S. M. Lindsay, Oxford University Press (2010).

Thin Film Deposition and Vacuum Techniques – E29

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Thin Film Deposition Techniques: Introduction – Kinetic theory of gases, Physical vapour deposition techniques, Physics and Chemistry of evaporation, thermal evaporation; pulsed laser deposition, molecular beam epitaxy, sputtering deposition, direct Current, Radio Frequency, Magnetron. Ion beam and reactive sputtering – Chemical methods, Thermal Chemcial Vapour Deposition, Plasma enhanced Chemcial Vapour Deposition; Spray Pyrolysis, sol gel method, spin and dip coating, Electrophoretic and electrochemical deposition. Self-assembled monolayers. **10 Lectures**

Nucleation Growth and Epitaxy: Substrate surface, Adsorption, Surface energy, film growth modes, nucleation model, manifestations of epitaxy, lattice misfit and defect formation, morphology, grain growth, texture, microstructure control. **6 Lectures**

Diffusion, Reactions, Transformations and Stress: Fundamentals of diffusion – Grain Boundary Diffusion, metal-semiconductor reactions; phase transformations; origin of Thin film stress – Classifications of stress, stress in epitaxial films, growth stress in polycrystalline films; Correlation between film stress and grain structure, mechanisms of stress evolution, film stress and substrate curvature, Stoney formula; methods of curvature measurement – Scanning laser method. **10 Lectures**

Thin Film Characterization Techniques: Glancing angle XRD. Auger Electron spectroscopy – Photoelectron Spectroscopy – Secondary Ion Mass Spectroscopy –Rutherford Backscattering spectroscopy - Ellipsometry – Profilometry, Low Energy Electron Diffraction – Reflection High Energy Electron Diffraction. Scanning Electron Microscopy, Transmission Electron Microscopy, Atomic Force Microscopy and Energy Dispersive X-ray analysis of thin films. **8 Lectures**

Vacuum Techniques: Theories of gas flow, basic principles and processes for production of vacuum and ultra-high vacuum. Vacuum pumps – a survey; Diaphragm pump, Rotary vane pump, Diffusion Pump, Turbomolecular Pump (TMP), Sorption pumps: Adsorption pumps, Sublimation pumps, Sputter-ion pumps; Cryo Pump. Measurement of vacuum - Thermal conductivity vacuum gauges, Types pressure gauges. Metal and Neoprene Gasket, Analysis of gas at low pressures: Residual gas analyzers, Leaks and their detection: Types of leaks, Leak rate, leak size; Leak detection methods. Halogen and Helium leak detectors. **10 Lectures**

Thin Film Devices: Charge and spin in single quantum dots- Coulomb blockade. Single electron transfer devices (SETs), Electron spin transistor, resonant tunnel diodes, tunnel FETs, quantum interference transistors (QUITs) - quantum bits (qubits). Thin film high K MOSFET device structures. **6 Lectures**

Suggested References:

1. Thin Films - High density Plasmas, Volume 27 – A.E. Wendt, Springer Publishers (2006).
2. Hand Book of Deposition technologies for Thin Films and coatings by Science, Technology and Applications, Second Edition – R.F. Bunshah, Noyes Publications
3. Materials Science of Thin films – M. Ohring, Academic Press Limited(1991)
4. Thin Film Materials - L.B. Freund, S. Suresh (2003).
5. Solid surfaces, Interfaces and Thin Films – H. Luth, Springer Publishers (2010).

6. Physics of Surfaces and Interfaces, H. Ibach, Springer Publishers (2006).
7. Thin Film Phenomena – K.L. Chopra, Mc Graw-Hill (1969)
8. Fundamentals of Vacuum Technology – W. Umrath,
https://www.academia.edu/29289669/Fundamentals_of_Vacuum_Technology

Preparation and Characterization of Nanomaterials – E30

Elective Course, 90 Hours

List of Experiments:

1. Synthesis of metal nanoparticles by chemical route.
2. Synthesis of semiconductor nanoparticles.
3. Surface Plasmon study of metal nanoparticles by UV-Visible spectrophotometer.
4. XRD pattern of nanomaterials and estimation of particle sizes from given data set.
5. Study the Scanning Electron Microscope, Atomic Force Microscope topographs of thin film and estimations of different parameters from given data sets.
6. Study the crystallite size from given SAED pattern of a TEM micrographs and compare the results with XRD study of same material.
7. To study the effect of size on color of nanomaterials.
8. Prepare a disc of nanomaterials, pressing and sintering, and study its XRD.
9. Fabricate a thin film of nanoparticles by spin coating (or chemical route) and study transmittance spectra in UV-Visible region.
10. Prepare a thin film capacitor and measure capacitance as a function of temperature or frequency.
11. Fabricate a PN diode by diffusing Al over the surface of N-type Si and study its V-I characteristic.
12. To prepare composite of CNTs with other materials.
13. Growth of quantum dots by thermal evaporation.

Computation Laboratory based practicals will be introduced later.

Suggested References:

1. Introduction to Nanoscience & Technology - K.K. Chattopadhyay and A.N. Banerjee, Prentice-Hall Of India Pvt. Limited.
2. Electronic Structure: Basic theory and practical methods – R. Martin, Cambridge University Press, 2004.
3. Chemistry of Nanomaterials: Synthesis, Properties and Applications Vol.1 and Vol 2 - CNR Rao, et al, Wiley.
4. Novel Synthesis and Characterization of Nanostructured Materials (Engineering Materials) – A. Alves, C.P. Bergmann, Springer (2013).
5. Handbook of Nanostructured Biomaterials and Their Application in Nanobiotechnology – H.S. Nalwa. American Scientific Publishers.

Mössbauer Spectroscopy and Its Applications – E31

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Mössbauer Effect: Introduction, recoil energy and recoil momentum, natural broadening, Doppler broadening, resonance fluorescence, Mössbauer experiment, resonance absorption of gamma-rays, elementary considerations, classical theory of Mössbauer effect, quantum mechanical theory, importance of Mössbauer's discovery, gravitational red shift. **12 Lectures**

Mössbauer Instrumentation: Introduction, sources, absorbers, detectors, Mössbauer velocity drive, low temperature cryostats, MIMOS, Mössbauer spectroscopy. **3 Lectures**

Applications of Mössbauer Spectroscopy

Study of Lattice Dynamics: Introduction, theoretical background, Debye-Waller factor, Lamb-Mössbauer factor, method of analysis of Mössbauer spectra, effect of atomic motion in solids and liquids. **7 Lectures**

Study of Chemical Binding: Introduction, isomer shift, electric quadrupole interaction, determination of chemical bond using isomer shifts, chemical bond and electrical quadrupole interaction, determination of magnetic moment from electrical quadrupole splitting. **8 Lectures**

Study of Magnetic Property of Solids: Introduction, magnetic hyperfine structure, origin of hyperfine field, relation between nuclear hyperfine field and saturation magnetization, study of different magnetic lattices. **7 Lectures**

Study of Spin Transition: Introduction, occurrence of spin transition, spin transition curves, iron(II) systems, detection of spin transition. **8 Lectures**

Study of Ferroelectrics: Introduction, Devonshire's theory of ferroelectric transition, Cochran's lattice dynamical theory of ferroelectricity, order-disorder transition, Mössbauer spectroscopy of perovskite ferroelectrics. **5 Lectures**

Suggested References:

1. Mössbauer Effect and Transition Metal Chemistry – P. Guetlich, E. Bill, A. X. Trautwein, Springer.
2. Introduction to Mössbauer Effect and Applications – V. G. Bhide, Tata-McGraw-Hill.
3. Introduction to Physical Techniques in Molecular Magnetism: Structural and Macroscopic Techniques – F. Palacio; E. Ressouche; J. Schweizer, Universidad de Zaragoza
4. Macroscopic Techniques – Edts. F. Palacio, E. Ressouche, J. Schweizer, Universidad de Zaragoza
5. Spin Crossover in Transition Metal Compounds I - Edts. P. Guetlich, H. A. Goodwin, Springer.

Nulcear Astrophysics – E32
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Introduction to Nuclei in Cosmos: Observational foundation, Hertzsprung-Russell diagram (HRD), Electromagnetic spectra and abundance determinations, Composition of the solar system, Stellar reaction rates, Reaction cross-section and Astrophysical S-factors, Resonant and non-resonant reactions, Breit-Wigner Formula, Hoyle state, Thermonuclear reaction, Maxwell-Boltzmann velocity distribution, Gamow peak, Gamow window, Resonance strength.
10 Lectures

Big Bang Nucleosynthesis: Hot modes of hydrogen burning, p-p reaction, hot CNO cycles and NeNa-MgAl chains, Abundance of light elements, Be bottleneck, Creation and survival of ^{12}C.
8 Lectures

Stellar Structure: Classical star, electon and neutron degeneracy, Main Sequence stars, Stellar evolution, Newtonian form of hydrostatic equilibrium - Lane-Emden equation. **5 Lectures**

Nuclear Burning in Stars: Stellar evolution, Hydrogen burning, Helium burning and s-process, Carbon burning, Advanced nuclear burning, core collapse, solar neutrino problem, neutrinos as solar thermometer. **7 Lectures**

Stellar Nucleosynthesis: Abundance curve, stellar nuclear reaction network, Production of nuclei beyond Fe, Supernovae, s-, r-, and i-processes, White Dwarf and Neutron star, Chandrsekhar limit. **8 Lectures**

Experimental Tools and Techniques in Nuclear Astrophysics: Direct and indirect cross-section measurements, Indirect methods – Coulomb dissociation, Asymptotic Normalization Coefficients (ANC), and Trojan Horse method (THM), Nuclear astrophysics research facilities worldwide, Requirement for Low energy high current accelerators, estimation of possible contaminating background radiation sources and reduction techniques, Application of Radioactive beams in nuclear astrophysics, detector facilities. **12 Lectures**

Suggested References:
1. Nuclear Physics of Stars – C. Iliadis, Wiley-Vch, 2007
2. An Introduction to Nuclear Astrophysics – R.N. Boyd, University of Chicago Press, 2008
3. Nuclear Reactions for Astrophysics, I.J. Thompson and F.M. Nunes, Cambridge University Press, 2009
4. Principles of Stellar Evolution and Nucleosynthesis – D.D. Clayton, University of Chicago Press, 1983
5. Cauldrons in the Cosmos: Nuclear Astrophysics – C.E. Rolfs, W.S. Rodney, University of Chicago Press, 1988
6. An introduction to the Study of Stellar Structure – S. Chandrasekhar, Dover Publications, 2003

Biophysics I – E33
Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Basic Information of Biology: Cell structure, the cell membrane, cell organelles, cell life cycle; lipids, proteins, nucleic acids, carbohydrates, biomolecules: functional groups carbohydrates, proteoglycans and glycoproteins. **7 Lectures**

Protein Folding and DNA: Factors influencing protein structure, membrane proteins, polypeptide backbone, bond angles, common protein secondary structures; nucleic acid, DNA secondary structure, DNA melting, DNA tertiary structure. **8 Lectures**

Charged Ions and Polymers: Ions in aqueous solution – the Debye-H¨uckel relation, ionic radius, the behaviour of polyelectrolytes, Donnan equilibria, Poisson-Boltzmann theory for cylindrical charge distributions. **8 Lectures**

Information Theory and Entropy: Shannon, Boltzmann, Schr¨odinger, Maxwell's daemon, Application to biological systems like DNA; biological structure: general Aspects. Energy of activation, theory of Absolute reaction rate. **4 Lectures**

Surface and Transport Phenomena: Interfacial phenomena and membranes; biological membranes – molecular structure, mechanical and electrostatic properties; transport mechanism, ion transport; Electrokinetic phenomena **6 Lectures**

Motility: Energetics and dynamics of biological systems, thermodynamics applied to biological systems, entropy and stability, Glansdorff-Priogogine principle, thermodynamic basis of biochemical reactions. aqueous and ionic equilibrium of the living cell, Donnan equilibrium; thermodynamics of diffusion processes: Fick's laws of diffusion, Filtration, Diffusion of ions, diffusion potential. **5 Lectures**

Perception: Photon counting in vision — animal eyes; fluids in the body, pressure in blood vessels, laminar flow in aorta, ventilation system; locomotion — process of flying, walking, running etc., sports physics; sound perception — voice and hearing in animals, bats; body electronics and magnetic senses — conduction of nerve pulses, gates in cells, electrical signals of muscle activities, electrical detection of prey, fish; navigation of migratory birds, magnetic senses. **12 Lectures**

Suggested References:

1. Biophysics: An Introduction – R. Cotterill, John Wiley & Sons
2. Biophysics: searching for principles – W. Bialek, Princeton University Press
3. Biophysics – R. Glaser, Springer

Biophysics II – E34

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Population Models: Single species continuous growth models – outbreak model, delay models, harvesting and age distribution; single species discrete population models — simple models, discrete logistic, stability; fishery management model, ecological implications, tumor cell growth; interacting population models — Lotka-Volterra systems, complexity and stability, realistic predator-prey models, mutualism or symbiosis. **12 Lectures**

Pattern Formation: on growing domains, fractals and biological significance, animal coat patterns, bacterial patterns and chemotaxis, model mechanism for E. coli in the semisolid experiments, mechanical theory for generating pattern and form in development, epidermal and dermal wound healing models. **11 Lectures**

Biological Oscillators: switches and reactions: two-species oscillators, determination for oscillations, various modeling; stability analysis various oscillating reaction, nonlocal stability, perturbed and coupled oscillators; phase resetting in oscillators, phase locking of oscillations, curves, black holes in real biological oscillators. **7 Lectures**

Dynamics of Infectious Diseases: simple epidemic models, modeling venereal diseases, multigroup model for gonorrhea and its control; AIDS: modeling the transmission dynamics of the Human Immunodeficiency Virus (HIV), drug therapy, modeling the population dynamics of acquired immunity to parasite infection, Bovine tuberculosis Infection; growth and control of brain tumors. **12 Lectures**

Biological Waves: Diffusion equation, models for animal dispersal, chemotaxis, cell potential, oscillator-generated wave, biological waves of single-species models, FisherKolmogoroff equation, spread and control of an insect population. **8 Lectures**

Suggested References:

1. Mathematical Biology, An Introduction – J.D. Murray, Springer
2. A Primer on Mathematical Models in Biology – L. Edelstein-Keshet, Society for Industrial & Applied Mathematics
3. Mathematical Models in Biology – L. Edelstein-Keshet, Society for Industrial & Applied Mathematics
4. Mathematical Biophysics – A. Rubin, G. Riznichenko, Springer
5. Mathematical Aspects of Pattern Formation in Biological Systems – J. Wei, M. Winter, Springer

Non-Equilibrium Thermodynamics – E35

Elective Course; Lectures – 50 Hours, Tutorial – 10 Hours

Review of Thermodynamics: State variable and equation of state, Laws of thermodynamics, Thermodynamic potentials, Gibbs Duhem and Maxwell relations,response function,condition of equilibrium and stability, thermodynamics of phase transitions, the probability distribution of fluctuations. **5 Lectures**

Reversible Process and the Maximum Work Theorem: Possible and impossible process, quasi-static and reversible processes, heat flow: coupled systems and reversal of processes, the maximum work theorem, measurability of temperature and of the entropy. **4 Lectures**

Thermodynamics of Critical Phenomena: Thermodynamics in the neighborhood of critical point, divergence of stability, order parameter and critical exponent, classical theory in the critical region, Landau theory, Ginzberg Landau theory of superconductivity. **12 Lectures**

Irreversible Thermodynamics: Affinity and fluxes, Purely resistive and linear systems, the theoretical basis of Onsager reciprocity, thermodynamics of simple fluids, transport coefficients and Navier Stokes equation, relation between viscosity and diffusion, Lord Kelvin model. **10 Lectures**

Elementary Theory of Transport: Boltzmann Lorentz model, Boltzmann equation, transport coefficient from the Boltzmann equation. **5 Lectures**

Statistical Entropy and Boltzmann Description: Statistical entropy, Boltzmann distribution, Irreversibility and growth of entropy. **2 Lectures**

Elementary Probability Theory: Stochastic variables and probability, Binomial distribution, Central limit theorem and laws of large numbers, random walk in one and higher dimensions, General form of infinitly divisible distribution, Levy-Khintchine formula, Kolmogorov formula **5 Lectures**

Stochastic Dynamics and Brownian Motion: Markov chains, Master equation, Brownian motion, Langevin equation, spectral density (power spectrum), Fokker-Plank equation, Fokker-Plank equation with several variable: SIR model **7 Lectures**

Suggested References:

1. Statistical Mechanics – K. Huang, John Wiley & Sons
2. Equilibrium Statistical Physics – M. Plischke, B. Bergersen, World Scientific
3. Non-Equilibrium Thermodynamics – S.R. deGroot, P. Mazur, Dover Publications
4. A Modern Course in Statistical Physics – L.E. Reichl, Wiley-VCH

Instrumentation for Experiments – E36

Elective Course; 90 Hours

A student will study the basics of instrumentation and build one instrument and do the corresponding experiment.

1. Construction of a PID temperature controller using analog components.
2. Construction of a PID temperature controller using digital components.
3. Construction of a Lock-in-Amplifier using CD4066 and supporting circuitry.
4. Construction of a coil system and using the Lock-in-Amplifier to study the Meissener effect in a high T_C superconductor.
5. Construction of a capacitance meter using a Lock-in-Amplifier and to determine the dielectric constant of different liquids at varying temperature.
6. Construction of an ultra-stable current controller using micro-controllers.

More experiments will be added later.

Suggested References:

1. Instrumentation, A.V. Bakshi and U.A. Bakshi, Technical Publications, 2009.
2. Basic Electronics for Instrumentation, P. H. Sydenham, Instrument Society of America.
3. Microcontroller-based Temperature Controller and Control, Dogan Ibrahim, Newnes.

Advanced Experimental Techniques – E37

Elective Course; Lectures – 50 Hrs, Tutorial – 10 Hrs

Instrumentation: Converting different physical properties into electrical signals and vice-versa – temperature, humidity, light intensity, pressure/force, mechanical displacement (proximity sensor, etc.) light spectrum/ colour, magnetization (DC), susceptibility (AC & DC), dielectric constant, different types of radiations (α, β, γ) **10 lectures**

Proportional-Integral-Derivative (PID) Algorithm and Elements of Control Theory 10 Lectures

Data Analysis: uncertainties, genetic algorithms, multivariate analysis – random forests, machine learning techniques **10 Lectures**

Interfacing and Networking: Instrument-computer interfacing, networking, remote monitoring and controlling of instruments, troubleshooting. **10 Lectures**

Instruments: RF SQUID, Bose-Einstein Condensation set up, microscopes, NMR **10 Lectures**
OR,
Advanced topic: To be decided by the instructor **10 Lectures**

Necessary references and documents will be provided during the course.