Paper-11

Choice Based Topics and Relativistic Quantum Mechanics

<u>Group A: Choice Based Topics (CBCS)</u>

Proposed Topics for Choice Based Papers (CBCS):

1) Plasma Physics [36 lectures]

Introduction: Definition of plasma, occurrence in nature, concept of temperature, particle interactions and collective effect, macroscopic neutrality, criteria of a plasma, plasma parameter, applications of plasma

[3L]

Basic plasma phenomena - Quasineutrality, Debye shielding, plasma oscillations

[3L]

Single particle motions: Motion of charged particle in uniform electrostatic and magnetostatic fields, magnetic moments, Charged particle motion in time-varying electric field, plasma dielectric constant, non-uniform magnetic fields, gradient & curvature drift, magnetic mirrors, magnetic confinement of plasma, adiabatic invariants. magnetic heating of plasma

[10L]

Magnetohydrodynamics : Conducting fluid in a magnetic field, Generalized Ohm's law, MHD equations, magnetic viscosity, magnetic Reynold's number, magneto-hydro-dynamic generator

[4L]

Non-linear effects : Plasma sheath, Bohm Sheath criterion, Child-Langmuir law, plasma probe.

[4L]

Waves in plasma : Plasma oscillations, electron plasma waves, Langmuir waves, ion waves. Ion-acoustic waves, electrostatic electron oscillations and ion waves normal to magnetic field, electromagnetic wave propagation through plasma, ordinary and extraordinary waves, right and left circularly polarized waves, cut-offs and resonances, hydromagnetic or Alfven waves

[12L]

Reference Books:

1. Fundamentals of Plasma Physics, J. A. Bittencourt (Springer)
2. Introduction to Plasma Physics and Controlled Fusion, F. F. Chen (Springer)
3. Plasma Physics – An Introduction, R. Fitzpatrick (CRC Press)
4. Introduction to Plasma Physics, R. J. Goldston & P. H. Rutherford (IOP)

2) Physics of Biological systems [36 lectures]

Preliminaries:

The building blocks: Proteins, Lipids, Nucleic Acids, Carbohydrates, Water, Proteoglycans and Glycoproteins. Cells, Viruses and Bacteria

[3 L]

Soft Condensed-Matter Techniques in Biology:

Introduction to Statistics in Biology: Statistics, Entropy, Information, Temperature, Free Energy, Partition Function, Open systems and Microscopic systems.

[5 L]

Mesoscopic Forces: Cohesive Forces, Hydrogen Bonding, Electrostatic interactions. Electrostatics for salty solutions. Brief overview of biological electricity. Steric and Fluctuation Forces. Life in crowded environments, Depletion Forces. Hydrodynamic Interactions. Microscopic view of entropic forces. Osmotic pressure and Osmotic flow. Direct Experimental Measurements of Intermolecular and Surface Forces.

[8 L]

Statistical view of biological dynamics: Diffusion, Low Reynolds Number Dynamics, bacterial flagella. Random walks and macromolecules, Brownian motion, other random walks, Biological applications of diffusion. First Passage Problem, Rate Theories of Chemical Reactions and rate equations, motors and filaments.

[7 L]

Chemical forces and Aggregating Self-Assembly: Chemical potential and chemical reactions, Dissociation, Surfactants, Viruses, Self-Assembly of Proteins, Polymerisation of Cytoskeletal Filaments, Self-assembly of amphiphiles, Self-assembly in cells.

[7 L]

Recapitulations: Surface Phenomena (Surface Tension, Adhesion, Wetting, Capillarity) and Fluid Mechanics (Newton's Law of Viscosity, Navier–Stokes Equations, Pipe Flow).

[3 L]

Vascular Networks, Haemodynamics, Circulatory Systems, Lungs

[3 L]

Reference Books:

1. Tom A. Waigh, Applied Biophysics: A Molecular Approach for Physical Scientists

2. Philip Nelson, Biological Physics: Energy, Information, Life

3. Thomas A. Waigh, The Physics of Living Processes - A Mesoscopic Approach

4. Howard C. Berg, Random Walks in Biology

5. R. Phillips, J. Kondev, J. Theriot and H. G. Garcia, Physical Biology of the Cell

3) Phase Transition and Critical Phenomena **[36 Lectures]**

Examples of classical and quantum critical phenomena in various systems, Brief review of Thermodynamic potentials, Heat capacity and Magnetic susceptibility, Definition of Thermodynamic Phase

[8L]

Phenomenology of 1st order phase transitions. Continuous transitions, Landau Ginzberg theory. Order Parameters and Spontaneous symmetry breaking. Critical Behaviour, Scaling, Critical Exponents and relations between them.

[16L]

Models: Transfer Matrix theory, Ising model in 1-d, Pott's model. Universality and RG (Qualitative discussions)

[12L]

Reference Books:

1. H.E. Stanley, Introduction to phase transition and critical phenomena
2. S.K. Ma, Modern Theory of Critical Phenomena
3. Yeomans, J. P.: Statistical Mechanics of Phase Transitions
4. Nishimori & Ortiz, Elements of Phase Transitions and Critical Phenomena (Oxford Graduate Texts)

4) Physics of soft matter [36 Lectures]

Soft matter: Introduction and Overview on soft matter systems : liquid crystals, colloidal systems, biological membranes, macro- molecules.

[2L]

Forces, energies and time scales in condensed matter, Gases, liquids and solids - intermolecular forces, condensation and freezing. Viscous, elastic and visco-elastic behaviour response of matter to a shear stress

[4L]

Macromolecules : DNAs-: Flory's model of DNA condensation; Polymorphism of liquid crystal states by low molecular mass double stranded DNA complexes; DNA condensation in water-polymeric solution; biological activity, Numerical methods for studying soft matter

[5L]

Random walks, friction and diffusion: Brownian motion, other random walks: diffusion in the sub cellular world, equation for diffusion, precise statistical prediction of random processes, biological applications of diffusion.

[6L]

Colloidal dispersions: Introduction, single colloidal particle in a liquid, Stokes' law, Brownian motion and Stokes-Einstein equation. Forces between colloidal particles – inter-atomic forces and inter-particle forces, van der Waals forces, electrostatic double layer forces. Self assembly in soft condensed matter: Introduction, self assembled phases in solutions of ampiphilic molecules.

[8L]

Soft matter in nature: Biological polymers, nucleic acids, nucleic acid conformation – DNA, RNA, Proteins, stretching single macromolecules, Protein folding.

[4L]

Enzymes and molecular machines: Molecular devices found in cells, purely mechanical machines, molecular implementation of mechanical principles, kinetics of real enzymes and machines.

[4L]

Biological membranes: Electrosmotic effects, ion pumping, mitochondria as factories, powering flagellar motors.

[3L]

Reference Books:

1) Soft Condensed Matter, Richard AL Jones, Oxford University press, 2002.
2) Biological Physics, Energy, Information, Life, Philip Nelson, 2002.
3) Principles of Condensed Matter Physics, PM Chaikin and TC Lubensky, Cambridge University press, 1995.
4) Biophysics - An Introduction, Rodney Cotterill, John Wiley, 2003.

5) Physics of Nanomaterials **[36 Lectures]**

Introduction to Nanoscience & Nanotechnology: Milestones in the development, Interdisciplinary nature, Synthesis of nanomaterials & nanostructure fabrication: Top down & Bottom up approaches, Self assembled monolayers. Synthesis of Nanowires, Nanoparticles for biological application, Nanomaterials toxic to Biological systems.

[12 L]

Physics of Nanostructures: 3D, 2D, 1D and 0D; Heterostructures - Band bending, depletion width and capacitance, inversion layer, 2D electron gas in triangular well; sub band, density of states, surface electron density; exciton, quantum size effect, electron confinement - strong and weak limit; spherical well, effects of confinement; electronic properties of 2D materials like Graphene, Bio-nanointerface, Fullerene, Carbon Nanotubes (CNTs) – Physics & Technology.

[14 L]

Basic principle of experimental techniques for nanostructure characterization, Electron Microscopy: TEM, SEM, STEM, AFM, XPS, EDX, Electron diffraction (ED), Particle size measurement using TEM, XRD and light scattering.

[10 L]

Reference Books:

1. An Introduction to Nanoscience and nanotechnology: Alain Nouailhat, Wiley, 2006
2. Introduction to Nanoelectronics: Mitin, Kochelap & Stroscio, CUP, 2009
3. Introduction to Nanotechnology: Charles P Poole Jr. & Frank J. Owens, Wiley, 2003

6) Advanced Electronics **[36 Lectures]**

Theory:

CMOS technology and beyond:

CMOS inverter as a building block to digital and analog VLSI design; Small signal mathematical model; Cascode amplifier, differential amplifier, Gilbert Cell, CMOS digital design – PUN/PDN, Transmission Gate. Memories: CMOS –SRAM, DRAM, PROMs, Scaling of MOS transistors – limits of Moore's Law; New research area in IC technology (CMOS and beyond).

[15L]

Microcontrollers and embedded systems (salient ideas)

Electronic Communication and signal processing:

Analog and Digital Communication- Modulation Techniques (AM, FM, PM, Pulse Modulation, ASK, FSK, BPSK), PLL, Time and Frequency Multiplexing, Antenna (brief idea).

[10L]

Digital signal processing, Z transforms, Digital filters.

Circuit simulation and HDL software:

OrCAD PSpice & LTSpice. Verilog/VHDL for FPGA (Field Programmable Gate Array)

[6L]

Practical: (20 marks)

To be done as a Project – Any One

1) Circuit Design using LTSpice/OrCAD

2) Digital design implementation using Verilog/VHDL with FPGA

3) Electronic Communication highlighting modulation/multiplexing.

[5L]

Reference Books:

1. CMOS Analog Circuit Design by Allen & Holberg

2. CMOS Analog Circuit Design by Behzad Rezavi

3. CMOS Digital Circuit Design by Kang & Leblebici

4. Electronic Communication by Kennedy

5. Electronic Communication by BP Lathi

6. Electronic Communication by Roddy and Coolen

7. Advanced Digital Design with the Verilog (TM) HDL, by Michael D. Ciletti.

8. Verilog HDL: A guide to digital design and synthesis, by Samir Palnitkar.

9. A Verilog HDL Primer, by J. Bhasker.

10. Circuit Analysis with PSpice – A Simplified Approach, by Nassir H Sabah

11. SPICE – A Guide to Circuit Simulation and Analysis Using PSpice by Paul W Tuinenga

12. The SPICE book by Andrei Vladimirescu

Group B: Relativistic Quantum Mechanics [36 Lectures]

Relativistic Quantum Mechanics: Klein-Gordon equation, Feynman-Stuckelberg interpretation of negative energy states and concept of antiparticles, Dirac equation, covariant form, adjoint equation, plane wave solution and momentum space spinors, spin and magnetic moment of the electron, non-relativistic reduction, helicity and chirality, properties of gamma matrices, charge conjugation, normalization and completeness of spinors, Lorentz transformation of the Dirac equation, bilinear covariants and their transformations under parity and infinitesimal Lorentz transformation, Weyl representation and chirality projection operators.

[16L]

Field quantization: Basic ideas, construction of conjugate momentum from Lagrange density, commutation relations for bosonic and anti-commutation relations for fermionic fields in terms of field and momentum or creation and annihilation operators, quantization of scalar and complex scalar fields.

[12L]

Introduction to Feynman diagrams by way of spinless electron - electron scattering, calculation of the matrix element and scattering cross section.

[8L]

Reference Books:

1. Bjorken, J.D.; Drell, S.D. (1965). Relativistic Quantum Fields (Pure & Applied Physics). McGraw-Hill.
2. Greiner, W. (2000). Relativistic Quantum Mechanics. Wave Equations (3rd ed.). Springer.
3. Gauge Theories in Particle Physics, Volume -1, From Relativistic Quantum Mechanics to QED (2013), by Aitchison and Hey. CRC Press
4. F. Halzen and A.D. Martin: Quarks and Leptons : John Wiley and Sons.
5. http://epx.phys.tohoku.ac.jp/~yhitoshi/particleweb/particle.html : Quantum Field theory for Non Specialists Lecture Notes.