Course: M.Sc (Physics)

Semester	4
Paper Number	18(MPHC4404)
Paper Title	Advanced and Soft Condensed Matter
No. of Credits	6
Course description/objective	**Group A:** The student will learn of superfluidity: manifestations, phenomenological theory, quantization of vortices, second sound and behavior of specific heat, critical velocity. The difference between 4He and 3He will be appreciated, the difference in the pairing mechanism with respect to pairing in cooper pairs discussed, the different phases in 3He discussed in terms of transition and anisotropy of ground state with respect to Fermi Energy level known Why the need to study correlation in many body system will be appreciated with respect to previous knowledge; the 1-dimensional Hubbard model discussed and Mott insulators known. The Kondo effect shall be appreciated qualitatively. **Group B:** The students shall recognize what may be defined as soft matter based on different length scales, response time scales, the different forces that help in self aggregation that is typical to soft matter. Stability of solutions, osmotic pressure wetting and spreading understood in terms of Free Energy minimization. Modelling schemes based on lattice model, random walk, should give confidence to simulate complex growth schemes and dynamics of particles., results discussed with respect to solution of appropriate PDEs and principles of statistical mechanics. Characteristics typical of colloids, liquid crystals and polymers shall be known; this will also enable the students to suitably model biological systems that have similar properties. Micellar aggregation discussed with respect to hydrophobicity- application to surfactants understood. Student should be able to distinguish between different self-similar systems and quantify in terms of Fractal dimension. Introduction to disordered systems: substitutional, interstitial and positional or topographical disorder. Understanding of Short and long-range order. Percolation model to study disordered system focusing on geometric phase transition. Study of Localization & delocalization transition.
Course Outcome	**Group A** CO1: introduce the experimental manifestations of superfluidity, similarities and dissimilarities with BE condensation CO2: Introduce 2 fluid model of Landau and explain how earlier experimental observations could be explained CO3: Quantization of vortices, second sound explained CO4: Calculation and theory of critical velocity and quasiparticle interaction, specific heat CO5: Describe difference between 3He and 4He CO6: Phase transitions in 3He , outline the experimental challenge of cooling system to order of 2-3mK CO7: Discuss the process of pair condensation and point out difference with mechanism of cooper pair formation CO8: discuss the different phases of 3He CO9: Discuss the Hubbard model in 1-dimension and its requirement over the tight

	binding model CO10: Introduce the Mott insulator and Kondo effect **<u>Group B</u>** CO1: discuss what qualifies as soft matter; discuss length and time scales, discuss the different forces that are responsible for soft matter characteristics CO2: Capillarity and wetting: Surface and interfacial tension, dynamics of wetting, shapes of droplets – solid substrates and liquid substrates, droplet spreading dynamics; CO3: Viscous, elastic and viscoelastic behaviour - response of matter to a shear stress, mechanical response of matter at a molecular level; Viscous fingering. CO4: . Liquids and Glasses -practical glass forming systems, Zachariasen criteria, relaxation time and viscosity in glass forming liquids, glass transition temperature, two state theory. CO5: Liquid crystals: Classification, Nematic liquid crystals order, singularity, elasticity, display application, lamellar properties, Cholesterics CO6: Lamellar systems– structures and properties, chiral systems, Smectics CO7: Columnar systems – structures and properties, phase transitions, preparation of liquid crystals and application to liquid crystal displays CO8: Polymers: random walks and dimension of polymer chains, viscoelasticity in polymers and the repetition model; CO9: Biological polymers: stretching single macromolecules, Protein folding. CO10: self assembly in soft condensed matter: Introduction, Self assembly in polymers. Fractals in polymers – disorder and scale invariance, random aggregation, diffusion limited aggregation , self assembled phases in solutions of ampiphilic molecules; Applications – soaps and detergents, thin films, foams and biological cells CO11: Introduction to disordered systems: substitutional, interstitial and positional or topographical disorder CO12: Understanding of short and long-range order CO13: Percolation model to study disordered system focusing on geometric phase transition

Syllabus	**<u>Group A:</u>** **Advanced Condensed Matter Physics[36 Lectures]** Superfluidity: Superfluid Helium 4 : Basic Phenomenology; Transition and Bose-Einstein condensation; Two fluid model; Vortices in a rotating superfluid, Roton spectrum and specific heat calculation, critical velocity, Superfluid Helium 3: Basic Phenomenology; Pair condensation in a Fermi liquid, Superfluid phases of Helium-3 [12 lectures] Correlated Systems:Hubbard Model, Mott insulator, Kondo effect. [6 lectures] Disordered systems: Disorder in condensed matter: substitutional, interstitial and positional or topographical disorder; Short and long-range order; Anderson model; mobility edge; Minimum Metallic Conductivity, Qualitative application of the idea to amorphous semiconductors and hopping conduction. Percolation phenomena and the associated phase transition properties. [18 lectures]

	Group B: **Soft Condensed Matter Physics [36 Lectures]** Soft condensed matter: Introduction and Overview, Forces, energies and time scales in condensed matter, Forces and Energy scales: Atomic and molecular forces, van der Waals forces, Casimir forces, Hard core repulsion, Entropy. [3 lectures] Rheology: Capillarity and wetting: Surface and interfacial tension, dynamics of wetting, shapes of droplets – solid substrates and liquid substrates, droplet spreading dynamics; Viscous, elastic and viscoelastic behaviour - response of matter to a shear stress, mechanical response of matter at a molecular level; Viscous fingering. Liquids and Glasses -practical glass forming systems, Zachariasen criteria, relaxation time and viscosity in glass forming liquids, glass transition temperature, two state theory. [9 lectures] Liquid crystals: Classification, Nematic liquid crystals order, singularity, elasticity, display application, lamellar properties, Cholesterics, Lamellar systems– structures and properties, chiral systems, Smectics and Columnar systems – structures and properties, phase transitions, preparation of liquid crystals and application to liquid crystal displays. [8 lectures] Macromolecules: Polymers: random walks and dimension of polymer chains, viscoelasticity in polymers and the repetition model; Biological polymers: stretching single macromolecules, Protein folding. [8 lectures] Supra-molecular self assembly in soft condensed matter: Introduction, Self assembly in polymers. Fractals in polymers – disorder and scale invariance, random aggregation, diffusion limited aggregation , self assembled phases in solutions of ampiphilic molecules; Applications – soaps and detergents, thin films, foams and biological cells. [8 lectures]
References	**Group A:** 1. Solid State Physics by N. W. Ashcroft & N. D. Mermin 2. Solid State Physics by H. Ibach & H. Lüth 3. Introduction to Solids by L. V. Azaroff 4. Introduction to Superconductivity by M. Tinkham 5. Principles of the Theory of Solids by J. M. Ziman **Group B:** 1. Soft Condensed Matter, Richard A. L. Jones (Oxford University Press, 2002) 2. Structured Fluids: Polymers, Colloids, Surfactants, Thomas A. Witten (Oxford University Press, 2004) 3. Scaling concepts in Polymers, P. G. De Gennes (Cornell University Press, 1979) 4. Principles of condensed matter, Sections 1,2 and 6, P M Chaikin, T C Lubensky (Cambridge University Press, 1995)

	5. Soft Matter Physics: An Introduction, Maurice Kleman, Oleg D Laverntovich, J. Firedel, (Springer, 2000)
Evaluation	Total: 100 **Group A:** CIA: 10 End Semester Examination: 40 **Group B:** CIA: 10 End Semester Examination: 40