Course: M.Sc (Physics)

Semester	4
Paper Number	16 (MPHC4402)
Paper Title	Basics of Condensed Matter Physics
No. of Credits	6
Course description/objective	**Group A:** The main objective of this theory course is to introduce students to the applications of quantum mechanics in the context of a few important aspects of basic condensed matter physics. They will learn the quantized modes of lattice vibration (phonons) in terms of the creation and annihilation operators. With this concept and background, they will be expected to learn several topics: like the introduction of the polarization modes in three-dimensional crystals, the Mossbauer effect, neutron inelastic scattering and its role to access the excitation modes in a solid, etc. at a reasonably rigorous level. It is expected that they will also know about the anharmonic effect and its role, in the context of heat transport. The objective of the second part of the course is to introduce the students to a set of interesting quantum phenomena when a charge is placed in a constant magnetic field. It is expected that they will learn about the classical and quantum Hall effects, the Landau levels and Landau diagmagnetism; magnetoresistance and Van Alphen de Haas oscillations. These topics are expected to be at a less rigorous level than what could be achieved in a dedicated course on these topics. **Group B:** Explanation of the physical properties of many electron systems has been a traditional challenge to the condensed matter theorists. The students are offered the basic technical approach and thereby the conceptual skill development in the present course with the basics of DFT technique that is further offered in the computational lab course simultaneously.
Course Outcome	**Group A** CO1: The students will have a firm grip over the lattice vibrations in crystals and the associated concepts, like neutron inelastic scattering. CO2: The students will use creation and annihilation operators and be experienced in using the commutation relations. CO3: The students will develop the pre-requisite in taking research level theory courses on these topics. **Group B** CO1: Students can understand the basic meaning of many electron systems with the practical examples cited. CO2: A thorough revision of the operator method in quantum mechanics helps them to follow the theories later. CO3: Students will be able to write the Hamiltonian with approximations if any. CO4: The basic difference between the Hartree and Hartree Fock (HF) approach is made clear with the a few applications and relevant theorems. CO5: The basics of the Density Functional Theory (DFT) with H-K theorem and few modern approximations as LDA, GGA etc are elucidated and finally linked to the lab based computational physics course.

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<td>Syllabus</td>
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<u>Group A:</u>
Basics of Condensed Matter Physics 1[36 Lectures]

Lattice dynamics: Classical theory of lattice vibrations in 3-dimensions under harmonic approximation; Dispersion relation: acoustical and optical, transverse and longitudinal modes; Lattice vibrations in a monatomic simple cubic lattice; Lattice waves, vibrational modes and phonons; normal and soft modes; phonon-phonon interaction, Inelastic Neutron Scattering and lattice dynamical modeling; Neutron diffraction by lattice vibrations; Elastic constants of crystals, Mossbauer effect.

[16 lectures]

Electronic transport properties: The Boltzmann transport equation and relaxation time; Electrical conductivity of metals, impurity scattering, ideal resistance at high and low temperatures, Umklapp-processes; Electronic properties in a magnetic field; Hall effect and magnetoresistance in two-band model; K-space analysis of electron motion in a uniform magnetic field; Thermoelectric effects; Energy levels and density of states in a magnetic field; Landau diamagnetism; Cyclotron resonance, de Haas-van Alphen effect; Quantum Hall effect.

[20 lectures]

<u>Group B:</u>

Basics of Condensed Matter Physics 2 [36 Lectures]

Many-electron systems: Basic electron-ion Hamiltonian in a solid (Time dependent to Time independent); the adiabatic approximation; Self-consistent field approximation, single product and determinantal wave functions, Hartree and Hartree-Fock (H-F) theory: exchange interaction and exchange hole, Koopman's theorem; Occupation number representation: Many electron Hamiltonian in occupation number representation; H-F ground state energy; Inclusion of electron correlation via configuration interaction.

[18 lectures]

Density Functional Theory: Fundamentals of DFT, comparison with conventional wave function approach, 1-body and 2-body Reduced Density Matrix, Electron Density as the basic variable, Thomas- Fermi model as precursor of modern DFT; Hohenberg-Kohn theorems; Functionals and functional derivatives; Euler-Lagrange formulation; Kohn-Sham equation; Concept of N- and v-presentability; Exchange-Correlation energy functionals; LDA, GGA and beyond; Practical implementations of DFT; Basis sets : Plane Wave and localized. Triumphs and shortcomings of DFT for treating molecules, solids and nanomaterials.
[18 lectures]

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References	**Group A:** 1. N.W. Ashcroft and N.D. Mermin: Solid State Physics 2. M. Sachs: Solid State Theory 3. J.M. Ziman: Principles of the Theory of Solids 4. C. Kittel: Introduction to Solid State Physics **Group B:** 1. Quantum Theory of Molecules and Solids, J.C. Slater, Vol. IV (McGrawHill, New York, 1974). 2. Electronic structure and properties of solids, W.A. Harrison (Freeman, 1980). 3. "Theory of inhomogeneous electron gas", S Lundqvist and N.H. March, (Plenum, New York, 1983) 4. "Electronic Structure: Basic Theory and Practical Methods", Richard M. Martin (Cambridge University Press, 2004)
Evaluation	Total: 100 **Group A:** CIA: 10 End Semester Examination: 40 **Group B:** CIA: 10 End Semester Examination: 40