QUANTUM THEORY OF CONDENSED MATTER

By L.F. Tocchio and R.C. Iotti

Subject fundamentals:
The course provides theoretical tools for understanding the properties of aggregate quantum systems with huge number of particles. Reference system along the course will be the crystalline solid. Starting from the Schrödinger equation for its microscopic Hamiltonian, the low temperature properties of electrons and ions, together with their elementary excitations and ordered phases will be derived. As well as optical and transport properties of the solid in response to external fields.

Expected learning outcome:
Knowledge of the microscopic mechanisms and models for describing the behavior of ions, electrons and excitations in solids and other condensed matter systems, such as nanostructures or ultra cold gases in optical lattices. Knowledge of analytical and numerical techniques for their investigations. Ability to apply the tools to the study of various phenomena, such as magnetism, superconductivity, and quantum Hall effect.

Prerequisites:
Basic knowledges of quantum and statistical physics

Contents:
1. From condensed matter to solid state physics. The fundamental Hamiltonian of a solid in first quantization; the Born Oppenheimer approximation. The crystalline solid; Bravais and reciprocal lattice.
2. Review of basic concepts of quantum statistical mechanics. Second quantization, density matrix, grand canonical thermodynamic potential, chemical potential.
3. Free Fermi and Bose gases. Bose-Einstein condensation; superfluids.
4. Single electron approximation. The Sommerfeld model; Bloch theorem; bands and Fermi surface; weak potential and tight binding approximations; graphene bands.
5. Lattice dynamics. The dynamical matrix; phonons; optical and acoustic modes; the Debye model and specific heat.
6. Electron-phonon interaction. The electron-phonon Frölich Hamiltonian; polarons; the Holstein model; second order processes and effective electronic Hamiltonian
7. Electron-electron interaction in mean field. The Hartree-Fock approximation; the jellium model; screening and Thomas Fermi treatment.
8. Models for electron-electron interaction. Introduction to Fermi and Luttinger liquid theories. Mott insulator and the Hubbard model. Ferromagnetism and the Heisenberg Hamiltonian. Quantum phase transitions. Entanglement.
9. Conventional superconductors. The Cooper instability. BCS microscopic theory.
10. High Tc superconductors. Role of electron-electron interaction and modelization.
11. Numerical simulations: the quantum Monte Carlo technique.
12. Transport properties: Drude conductivity, thermal conductivity and Wiedemann- Franz law. Classical and Quantum Hall effect.
13. Optical properties. Macroscopic formulation of electrodynamics in dispersive media: complex refraction index, absorption coefficient and dissipated power. Microscopic formulation: interaction of electrons with electromagnetic radiation;

14. The concept of Nanostructures. K-dot-p theory, envelope function, quantum wells, wires and dots.

Delivery modes:
The course includes classroom exercises also with assisted numerical simulations.

Texts, readings, handouts and other learning resources
N. Ashcroft, and N. Mermin, Solid-State Physics, Harcourt College Publisher, 1976
H. Ibach and H. Lüth, Solid-State Physics, Springer, 4th edition, 2009
U. Mizutani, Introduction to the electron theory of metals, Cambridge Univ. Press, 2004
U. Roessler "Solid state theory", Springer Verlag, 2009
J. Solyom, "Fundamental of the physics of solids", Springer, 2007-2009
Lecture notes and slides will be provided by the lecturers

Assessment and grading criteria
The exam consists in two oral parts, with two questions each. Answers to all questions concur with equal weights in determining the final grade