Condensed Matter Theory

Resp. UE: Silke Biermann (PR Ecole Polytechnique)

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ECTS credits: 6

Language of instruction: English

Examination: written exam (50%), homeworks and/or oral participation (50%).

Description:

This course gives an introduction to a choice of topics in condensed matter theory. Starting from the basic notions of Bloch theory known from the introductory classes at Bachelor or 1st year master level, but extending them to include topological properties of matter, we make first steps in Green's function theory to describe excitations in interacting quantum systems, and explore collective phenomena and emergent properties of matter and their theoretical description.

Outline of the course:

I) Band theory (without interactions)

- Bloch theorem, Bloch waves, Bravais lattice
- Tight binding models in second quantized form
- Symmetries: time-reversal symmetry, particle-hole symmetry, chiral symmetry
- Beyond the mono-atomic crystal : crystal lattices with basis (ex:graphene)
- Metals, insulators (semi-conductors), semi-metals. Notion of band mass
- The free Fermi gas and its thermodynamical properties. Notion of density of states
- Dirac materials and Dirac matter: Examples of different densities of states and application to graphene. Introduction to topology in Dirac 2-band Hamiltonians (Dirac monopole, Berry phases, obstructions, Chern insulators, etc.)

II) Green functions

- Definition and link to spectroscopy
- Single-particles Green functions (T=0) for free fermions. spectral functions, interpretation using Lehman decomposition

III) Response functions

- Response function (T=0) for free fermions.
- Spectral decomposition and interpretation of Lindhard function (dynamic and static limit $\omega \to 0$): applications to static impurities and Friedel oscillations.
- RKKY interaction

IV) A first attempt to include interactions

- Justification and discussion of Hubbard-like Hamiltonians

- Electronic phase transitions : Mott, Peierls
- Impurities in solids : Anderson Hamiltonian and mean field treatment. Self-energy, some notions on the Kondo effect

V) Collective effects

- Magnetism : Stoner magnetism, Hund's rules, local moments, magnetic order.-
- Heisenberg model.
- Bosonic quasi-particles : Phonons, magnons, plasmons
- Electron-phonon interaction (including derivation); electronic self-energy in the weak coupling regime. A word on polarons and strong coupling

VI) Fermi liquid theory

- Notion of (fermionic) quasi-particles: a phenomenological approach.
- Elements of Fermi liquid theory : Perturbative approach, mass renormalization, quasi-particle weight.
- Instabilities of the Fermi liquid (Cooper)

VII) Outlook : What is the present status of dealing with interactions ?