FSI3210 Many Particle Physics 7.5 credits

Mångpartikelfysik

This is a translation of the Swedish, legally binding, course syllabus.

If the course is discontinued, students may request to be examined during the following two academic years

Establishment

Course syllabus for FSI3210 valid from Spring 2016

Grading scale

Education cycle

Third cycle

Specific prerequisites

Good knowledge about all compulsory physics courses and statistical mechanics.

Language of instruction

The language of instruction is specified in the course offering information in the course catalogue.

Intended learning outcomes

After completed course, the PhD student should be able to:

- use second quantization formulation of quantum field theory.
- use Green's function technique.
- use Feynman diagrams.
- master the theories for the electron gas, superconductivity (BCS theory), and for superfluids.
- master the theoretical background for magnetism.

Course contents

Course main content

Part 1.

The first part of the course is devoted to explain basic formalism of the many body theory. It starts from the second quantization representation of quantum mechanical operators acting in the Hilbert space of a system consisting of many identical particles. Based on this technique the Green's functions are introduced and then their analytical properties are discussed. The perturbation theory and Feynman rules are discussed both for the ground state and equilibrium systems at finite temperatures, fermions and bosons. The linear response theory is introduced.

Part 2

During the second part of the course the general formalism will be applied to several examples of collective phenomena in condensed matter systems. The microscopic physics of superconductivity will be discussed in detail. Superfluidity in a weakly interacting Bose gas will be considered. The basic models of magnetism and spin-dependent collective phenomena like Kondo effect and RKKY interaction between magnetic impurities will be introduced.

Disposition

Lecture 1: Introduction. Simple examples demonstrating the importance of many body physics: Coulomb screening and plasma oscillations in metals. The concept of quasiparticles. Propagation function in single-particle quantum mechanics and its relation to the Green's function of the single-particle Schrodinger equation. Perturbation theory for the single-particle propagator. Feynman diagrams for potential scattering.

Lecture 2: Description of systems with a large number of identical particles. Fock's spaces and second quantization for the systems with Bose-Einstien and Fermi-Dirac statistics. Bosonic and fermionic field operators. Example: degenerate electron gas, cohesive energy and stability of metals. Causal Green's function of the many-body system. Relation to observables.

Lecture 3: Green's functions at zero temperature. Example of a free fermions system. Källén -Lehmann representation and analytical properties of causal, retarded and advanced Green's functions. Kramers-Kronig relations. Quasiparticles and the poles of retarded Green's function.

Lecture 4:Perturbation theory at zero temperature: Wick's theorem, Feynman rules. Cancellation theorem for disconnected diagrams. Self energy and Dyson's equation. Renormalization of particle interaction. Polarization operator. Example of Coulomb screening.

Lecture 5: Green's functions for equilibrium systems at a non-zero temperature. Generalized Källén -Lehmann representation and analytical properties of equilibrium Green's functions. Temperature (Matsubara) Green's functions, analytical continuation to the imaginary frequencies. Perturbation series and diagram technique for the temperature Green's functions.

Lecture 6. Linear response theory. Kubo formulas. Fluctuation-dissipation theorem. Onsager relations.

Lecture 7: Methods of the many-body theory in superconductivity. General picture of the superconducting state. Cooper pairing and instability of the normal state. Green's functions of a superconductor and Gorkov equations.

Lecture 8: Influence of impurity scattering on superconducting state and Anderson's theorem. Bogolubov- de Gennes equation for the spectrum of quasiparticles in superconductors. Andreev reflection of quasiparticles from the interface between normal and superconducting metals. .

Lecture 9: Quasiclassical theory of superconductivity. Microscopic Derivation of the Ginzburg-Landau equation for superconducting order parameter. Multiband superconductivity: superconducting state on the several sheets of the Fermi surface.

Lecture 11: Collective modes in normal and superconducting metals. Plasmons and Bogolubov-Anderson mode. Higgs bosons in superconductors. Leggett modes in multiband superconductors.

Lecture 10: Superfluid helium-4: general properties. Microscopic description of superfluidity in a weakly interacting Bose gas. Derivation of the Gross-Pitaevskii equation for the superfluid condensate wave function.

Lecture 11: Exchange interaction. Effective spin Hamiltonian. Stoner and Hubbard models of ferromagnetism. Kondo effect. RKKY interaction.

Course literature

Fetter och J. Walecka, Quantum theory of many particle systems, McGraw-Hill 1971.

A. A. Abrikosov, L. P. Gorkov och I. Y. Dzyaloshinskii, Quantum field theoretical methods in statistical physics, Pergamon, 1965.

A. Zagoskin, Quantum theory of many-body systems: techniques and applications, Springer-Verlag, 1998

R. White, Quantum Theory of Magnetism, Springer-Verlag, 2007

Examination

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

Other requirements for final grade

Hand in problems.

Ethical approach

- All members of a group are responsible for the group's work.
- In any assessment, every student shall honestly disclose any help received and sources used.
- In an oral assessment, every student shall be able to present and answer questions about the entire assignment and solution.