FEF3390 Quantum plasmas 8.0 credits

Kvantplasmor

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

Establishment

The official course syllabus is valid from the autumn 2026 as decided by the Faculty Board: dnr PA-2026-0008. Decision date: 2026-06-16.

Grading scale

P, F

Education cycle

Third cycle

Specific prerequisites

- Quantum mechanics (SI2380 Advanced Quantum Mechanics or equivalent)
- Statistical mechanics (SI1162 Statistical Physics or SI2510 Statistical Mechanics or equivalent)

Intended learning outcomes

After the course the student shall be able to

- explain concepts that are used for the theoretical description of the finite-temperature uniform electron gas;

- apply approaches that are used for the theoretical description of the finite-temperature uniform electron gas;
- debate the pros and cons of the density operator formalism, phase space formalism and second quantization formalism of quantum kinetic theory;
- estimate the thermodynamic, static, dynamic, phase transition properties of the finite-temperature uniform electron gas;
- apply the self-consistent dielectric formalism to the uniform electron gas and expand it to other homogeneous systems;
- assess the theoretical background for quantum plasmas and warm dense matter.

Course contents

- Elements of quantum statistical mechanics: bra-ket notation, commutator algebra, density matrix formalism (density operator, statistical ensembles, von Neumann equation, quantum BBGKY hierarchy), phase space formalism (Wigner-Weyl transform, Moyal bracket, von Neumann equation and quantum BBGKY hierarchy), second quantization (Fock space and occupation number representation, annihilation/creation operators for fermions and bosons, commutation rules, fermionic/bosonic field operators).
- Linear response theory: Kubo formula, Lehmann representation, Kramers-Kronig relations, fluctuation-dissipation theorem, properties of response functions, frequency moment sum rules, stiffness theorem, Matsubara summation, Fourier-Matsubara expansion, non-linear response extensions.
- Uniform electron gas (UEG): Convergent Hamiltonian, dimensionless parameters, zero-temperature phase diagram, warm dense matter, Wigner crystallization, magnetic phase transitions, charge density waves, spin density waves, roton minimum, low dimensionality extensions.
- Basic UEG properties: Microscopic quantities: number density, current density, spin-density and momentum flux density operators, density-density response theory, imaginary time correlation functions (ITCF), dynamic structure factor (DSF), static structure factor (SSF), radial distribution function (RDF), internal energy, adiabatic connection formula, compressibility sum rule, frequency moment sum rules (inverse, zero, fsum, third), Kimball cusp relations, current-current response theory extensions.
- Non-interacting UEG: Fermi-Dirac distribution, chemical potential, ideal Lindhard density response, long and short wavelength limits, high and low frequency limits, non-interacting DSF, non-interacting SSF, non-interacting RDF, non-interacting ITCF, low dimensionality extensions.
- Self-consistent dielectric formalism: Local field corrections (static or dynamic), building blocks of the dielectric formalism, random phase approximation (RPA), Singwi-Tosi-Land-Sjolander scheme (STLS) Vashishta-Singwi scheme (VS), convolution approximation (CA), hypernetted-chain based scheme (HNC), integral equation theory based scheme (IET), quantum STLS scheme (qSTLS) and quantum HNC/IET schemes (qHNC/qIET).
- Other formalisms: the Dharmawardana-Perrot classical mapping approach, the Dufty-Dutta classical mapping approach, sum rule approaches, continued fraction approaches, quantum kinetic theory and collision integrals, quantum hydrodynamics.

Examination

- INL1 - Linear response theory, 1.5 credits, grading scale: P, F
- INL2 - Uniform electron gas, 1.5 credits, grading scale: P, F
- INL3 - Dielectric formalism, 2.0 credits, grading scale: P, F
- SEM1 - Seminars on quantum plasmas, 3.0 credits, grading scale: P, F

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

Seminar presentations (3hp)

- Individual or in groups of two (student's choice).
- Peer grading.

Home assignments (5hp)

- Theoretical and numerical assignments.
- Individual and group work.
- Solutions discussed with teacher.

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.