Faculty of Health, Science and Technology
Physics

Syllabus

Quantum many-body physics - from entanglement to emergence

Course Code:	FYAD15
Course Title:	Quantum many-body physics - from entanglement to emergence *Kvant-mångkroppsfysik - från sammanflätning till emergens*
Credits:	7.5
Degree Level:	Master's level
Progressive Specialisation:	Second cycle, has second-cycle course/s as entry requirements (A1F)

Major Field of Study:
FYA (Physics)
TKA (Engineering Physics)

Course Approval
The syllabus was approved by the Faculty of Health, Science and Technology 2023-09-04, and is valid from the Spring semester 2024 at Karlstad University.

Prerequisites
90 ECTS credits in Physics, including Quantum Physics I, 7.5 ECTS credits, Solid State Physics, 7.5 ECTS credits, and Analytic Mechanics, 7.5 ECTS credits, plus 45 ECTS credits in Mathematics, including Linear Algebra, 7.5 ECTS credits, Calculus and Geometry, 7.5 ECTS credits, and Calculus in Several Variables, 7.5 ECTS credits, and registered for Symmetry - Mathematical Structures and Applications, 7.5 ECTS credits, plus upper secondary level English 6, or equivalent

Learning Outcomes

The aim of the course is for students to acquire both basic and in-depth knowledge of structures and methods used in quantum many-body physics.

Upon completion of the course, students should be able to:
- give an account of the emergence of quantum fields and their collective properties in problems related to quantum mechanical many-body systems,
- use second quantisation, coherent states, path integral, and Green's functions to solve problems in many-body physics,
- give an account of linear response theory and derive the Drude model for electrical conductivity,
- explain how Landau quasiparticles and collective modes emerge in Fermi liquids and argue for their stability or lack of stability,
- give an account of the basic phenomenology of superfluids and superconductors: apply the paradigms of BCS theory, spontaneous broken symmetry, and Higgs mechanism, explain the core concepts of the BKT phase transition and chiral pairing, and
- explain the basics of fractionalisation and quantum topological order and provide an overview of main theoretical approaches to quantum spin liquids.

Content
The course covers the following:
- Introduction to problems in quantum many-body physics: emergence and collective behaviour, second quantisation, quantum statistics from second quantisation
- Path integral formulation of quantum many-body problems: single-particle quantum mechanics from the path integral, partition function as a functional integral, coherent states and functional integrals
- Linear response theory: response functions, classical Drude formula for conductivity, calculations of electromagnetic linear response in quantum physics, f-sum rule
- Fermi liquid theory: Fermi liquid ground state, quasiparticles and their stability, collective modes, Landau damping, non-Fermi liquids, Green's function and self-energy
- Superfluids and superconductors: physical properties of superfluids and superconductors, BCS theory, spontaneous symmetry breaking and phase stiffness, vortices, the Higgs mechanism in superconductors, boson-vortex duality in two dimensions, the Berezinskii-Kosterlitz-Thouless transition, chiral superfluids and superconductors
- Quantum spin liquids and fractionalisation: the quantum Ising model, quantum antiferromagnetic order versus resonating-valence-bond state, emergent gauge fields and quantum spin liquids, Ising gauge theory, toric code model, fractionalised excitations and strings, quantum long-range entanglement and topological order

Reading List
See separate document.

Examination
Assessment is based on oral presentations and individual written reports, individual hand-in assignments, and an individual oral exam.

If students have a decision from Karlstad University entitling them to Targeted Study Support due to a documented disability, the examiner has the right to give such students an adapted examination or to examine them in a different manner.

Grades
One of the grades Distinction (VG), Pass (G), or Fail (U) is awarded in the examination of the

course. For Engineering students, one of the grades 5 (Pass with Distinction), 4 (Pass with Some Distinction), 3 (Pass), or U (Fail) is awarded in the examination of the course.

Quality Assurance
Follow-up relating to learning conditions and goal-fulfilment takes place both during and upon completion of the course in order to ensure continuous improvement. Course evaluation is partly based on student views and experiences obtained in accordance with current regulations and partly on other data and documentation. Students will be informed of the result of the evaluation and of any measures to be taken.

Course Certificate
A course certificate will be provided upon request.

Additional information
The local regulations for studies at the Bachelor and Master levels at Karlstad University stipulate the obligations and rights of students and staff.