

## Strongly Correlated Quantum Systems (C004071)

**Course size** *(nominal values; actual values may depend on programme)*

**Credits 6.0**                      **Study time 180 h**                      **Contact hrs**                      52.5h

**Course offerings and teaching methods in academic year 2022-2023**

A (semester 2)	English	Gent	lecture	42.5h
			seminar: coached exercises	7.5h
			project	2.5h

**Lecturers in academic year 2022-2023**

Haegeman, Jutho	WE05	lecturer-in-charge
Vanderstraeten, Laurens	WE05	co-lecturer

**Offered in the following programmes in 2022-2023**

	crdts	offering
<a href="#">Master of Science in Teaching in Science and Technology(main subject Mathematics)</a>	6	A
<a href="#">Master of Science in Teaching in Science and Technology(main subject Physics and Astronomy)</a>	6	A
<a href="#">Master of Science in Mathematics</a>	6	A
<a href="#">Master of Science in Physics and Astronomy</a>	6	A
<a href="#">Exchange Programme in Mathematics (master's level)</a>	6	A
<a href="#">Exchange Programme in Physics and Astronomy (Master's Level)</a>	6	A

**Teaching languages**

English

**Keywords**

Spin systems, quantum phase transitions, topological order, entanglement.

**Position of the course**

The goal of this course is to teach a number of general concepts and recent developments from the field of quantum many body physics, complemented by a modern point of view using the theory of entanglement.

**Contents**

- 1 Introduction: second quantisation, interacting electrons, the Hubbard model and its descendants
  - 2 Quantum Ising model in transverse magnetic field: exact solution via Jordan Wigner, Fourier and Bogoliubov transform. Quantum phase transitions and criticality. Order and disorder. Duality. Excitations and domain walls. Entanglement entropy: area laws and logarithmic divergence.
  - 3 Half-integer spin chains: Heisenberg antiferromagnets, Lieb-Schultz-Mattis theorem, order and disorder, Goldstone-bosons, Mermin-Wagner theorem, exact solution via coordinate Bethe ansatz.
  - 4 Integer spin chains: Haldane's conjecture, Affleck-Kennedy-Tasaki-Lieb model, introduction to MPS (Matrix Product States) and tensor networks. Gapless edge modes and symmetry protected topological order.
  - 5 Topological classification of free fermion systems: periodic table of topological insulators and superconductors, Su-Schrieffer-Heeger model and Kitaev's quantum wire: topological degeneracy and majorana edge modes.
  - 6 Spin models in higher dimensions, spin liquids, gauge theories and Kitaev's toric code model, topological order and anyons
- There will also be a group project, which can be chosen as either a literature review (e.g. quantum hall effect, Levin-Wen string net models, topological insulators,

entanglement renormalization for critical systems, entanglement entropy in conformal field theory, ...) or (density matrix renormalization group algorithm, tensor renormalization group, ...).

### **Initial competences**

Proper knowledge of quantum mechanics, basic knowledge of quantum field theory.

### **Final competences**

- 1 Familiarity with a number of basic concepts in quantum many body systems and condensed matter physics.
- 2 Having an overview about different phases of quantum matter, and the associated phenomenology (gapless edge modes, topological entanglement entropy,...)
- 3 Ability to read scientific papers about recent developments and to start research in this field.

### **Conditions for credit contract**

Access to this course unit via a credit contract is determined after successful competences assessment

### **Conditions for exam contract**

This course unit cannot be taken via an exam contract

### **Teaching methods**

Lecture, Project, Seminar: coached exercises

### **Extra information on the teaching methods**

Project: students make a literature review or a computational assignment in small teams. They make a report and a presentation about this work.

### **Learning materials and price**

Lecture notes and research papers  
Available via Ufora

### **References**

- Assa Auerbach, "Interacting electrons and quantum magnetism"(Springer, 1998)
- Eduardo Fradkin, "Field theories of Condensed Matter Physics"(2nd edition, Cambridge University Press, 2013)

### **Course content-related study coaching**

Outside lecture hours, the teachers are available for further explanation.

### **Assessment moments**

end-of-term assessment

### **Examination methods in case of periodic assessment during the first examination period**

Oral examination, Open book examination

### **Examination methods in case of periodic assessment during the second examination period**

Oral examination, Open book examination

### **Examination methods in case of permanent assessment**

Report

### **Possibilities of retake in case of permanent assessment**

examination during the second examination period is possible

### **Extra information on the examination methods**

- Periodic evaluation: Oral exam (with written preparation)
- Project: report and presentation

### **Calculation of the examination mark**

- 35% continuous assessment (project assignment)
- 65% end-of-term evaluation (oral examination)