DEPARTMENT OF PHYSICS

NFFY100, Quantum error correction, 7.5 credits

Kvantfelskorrigering, 7,5 högskolepoäng

Third-cycle level / Forskarnivå

Confirmation

This syllabus was confirmed by the Department of Physics on 2025-09-03, and was last revised on 2025-09-04. The revised course syllabus is valid from Autumn semester 2025.

Responsible Department

Department of Physics, Faculty of Science and Technology

Entry requirements

An introductiory course to quantum computing, e.g. FCC155(GU)/MCC155(Chalmers), is recommended.

Basic Python knowledge.

Learning outcomes

After completion of the course, the student will be able to:

Knowledge and understanding

- Be aware of algorithms for quantum error correction and their respective range of applications.

Competence and skills

- Be able to perform theoretical analysis of error correcting codes, and use decoder algorithms.
- Be able to implement and analyse the performance of simple codes in real quantum hardware.

Judgement and approach

-Understand limitations of theoretical studies of quantum error correction as applied to real quantum hardware.

Course content

Quantum error correction (QEC) is rapidly developing field which is at the center of current efforts in quantum computing, based on the realization that utlility-scale quantum computers need to have very low error rates. The course will give an introduction QEC with a focus on current and suggested future implementations in various qubit hardware platforms. Exercises will include theoretical problems as well as to implementing error correcting codes on quantum hardware.

The course will cover the following subjects:

- Stabilizer codes, repetition and surface code. Threshold theorem. Logical qubits, code distance, code ratio, Knill-Laflamme conditions.Error models. Depolarizing and biased Pauli errors, decay, leakage, cross-talk.
- Measurement-based quantum error correction.
- Logical gates on the surface code, including lattice surgery and magic state injection
- Advanced codes, such as surface codes tailored to bias noise (XZZX, Clifford-deformed codes), quantum low-density parity check (LDPC) codes, and concatentated codes such as dual-rail. Bosonic codes.
- Experimental implementations in various architectures, including superconducting discrete variable qubits, continuous variable qubits, ion traps, neutral atoms, and photonics-based systems.
- Decoding. Maximum-likelihood versus most-likely-error decoders. Minimum-weight perfect matching, belief propagation and machine learning based decoders.
- Ising model representation of stabilizer codes. Error threshold as a phase transition.

Types of instruction

Lectures, excercise help sessions, computer lab sessions.

Language of instruction

The course is given in English

Grades

The grade Pass (G) or Fail (U) is given in this course.

Types of assessment

Evaluation of students will be based upon: completion of exercises, completed project

Course evaluation

The course evaluation is carried out together with the Ph.D. students at the end of the course, and is followed by an individual, anonymous survey. The results and possible changes in the course will be shared with the students who participated in the evaluation and to those who are beginning the course.