# Experimental Quantul Computing and Quantum Error Corrections

**Winter 2025-26**

Quantum computing, i.e. the realization of calculation tasks using the resources of quantum physics, has the potential to perform some of them more efficiently than can be done on any classical computer. It can do so by using in a superposition, entanglement, interferences and measurement in a cunning way. Beyond this operational, applied promises, the field combines engineering of quantum systems challenges as well as the conceptual subtleties of quantum physics. It is thus a very rich field where physicists from different background have to combine efforts towards the goal of building a quantum computer.

This course is an introduction to quantum computing keeping a strong emphasis on recent experimental implementations. It will give detailed descriptions of the leading platforms such as atoms, ions, quantum circuits and photons and other emerging platforms. For each of them, their current status and limitations to be overcome will be discussed. We will also describe the leading quantum algorithms such as Shor's and Grover's, and discuss the resources required for their implementations.

A significant part of the course will be devoted to quantum error correction and the design of fault-tolerant architectures as these are the key step necessary to bridge the gap between the current physical errors on the qubits, around $10^{-3}$, and the error rate required for the implementation of quantum algorithms, likely to be below $10^{-10}$

**Lecturers**


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|---|---|
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**Lectures** Wednesday 14:00-17:15

**Web page of the course**

Lecture notes and materials, homeworks and articles will be posted here:
https://atom-tweezers-io.org/teaching/

**Tentative outline of the course**

**10/12 (AB)** Introduction to the course. History, qubits, quantum gates, quantum circuits. Parallelism and interferences. Idea of quantum errors and correction. Qubits in practice.

**17/12 (PS)** Atomic qubits: neutral atoms and trapped ions.

**07/01 (FM LR)** Superconducting qubits.

**14/01 (AB)** Photonic qubits and spin qubits based on electrons.

**21/01 (AB)** Quantum circuits 1: the modules. Quantum Fourier Transform, phase estimation…

**28/01 (PS)** Quantum circuits 2: Shor's and Grover's algorithms. Experimental implementations.

**04/02 (PS)** Introduction to quantum error correction: logical qubits. Stabilizers and surface code.

**11/02 (FM LR)** Quantum error correction 2: Logical operations and idea of fault-tolerance.

**18/02 (FM LR)** Quantum error correction 3: modules for fault-tolerant architecture and estimation of resources.

**Bibliography and extra materials**

The two first books approach the subjetc at a level comparable to the one of the course :

"Quantum Computing", Joachim Stolze, Dieter Suter, Wiley (2008).

"Quantum Information Processing: Theory and Implementation", Janos A. Bergou, Mark Hillery, Mark Saffman, Springer (2021).

More difficult:

"Quantum Computation and quantum information", M.A. Nielsen and I. Chuang, Cambridge (2010): much more detailed than the previous ones. The standard text but not really a textbook.

Lecture notes from M. Lukin (Harvard):
https://lukin.physics.harvard.edu/files/lukin/files/physics_160_notes.pdf

Lecture notes from J. Preskill (Caltech):
http://theory.caltech.edu/~preskill/ph219/index.html#lecture

Lecture notes from Scott Aaroson:
https://www.scottaaronson.com/qclec.pdf