Quantum Optics Technologies (QOT)

This course starts by introducing the fundamental aspects of quantum information and quantum optics. Using these tools, the second part of the program explores quantum algorithms, and their possible implementation in state-of-the-art quantum computers. Each topic will balance theoretical and problem-oriented sessions, that will be guided by the instructors of the course: Javier Argüello-Luengo (javier.arguello.luengo@upc.edu), and Iacopo Torre (iacopo.torre@upc.edu).

Syllabus

1. Fundamental concepts in Quantum Mechanics

- Definition of qubit, superpositions, and their representation in the Bloch sphere.
- Pure and mixed states. Density matrix
- Orthogonal and generalized measurements. POVMs.
- Entanglement. Schmidt decomposition. Bell states

2. Quantum information

- How different are two quantum states? Fidelity.
- No-cloning theorem
- Quantum entropy

3. Quantum computation

- Operators and quantum gates.
- Universal Basis. Pauli matrices, and their effect on the Bloch sphere.
    - 2-qubit gates: quantum CNOT, swap, CU gates.
    - 3-qubit gates: CSWAP, CCNOT, etc.
- Algorithms:
    - An academic example: The Deutsch algorithm.
    - Bell states and superdense coding.
    - Quantum Fourier Transform. Shor’s algorithm and its impact on RSA
    - Stabilizers and Grover’s algorithm
- Introduction to quantum error correction

4. Quantum hardware:

- What is a universal quantum computer? DiVincenzo's criteria.
- Computing architectures
  - Superconducting circuits: flux qubits, cryostats [Qiskit]
  - Atoms: laser, light-matter interactions, Rabi oscillation, optical traps, Rydberg blockade
  - Ion traps: Paul trap, sideband addressing
  - Photonic circuits: qubit codification, Hong-Ou-Mandel experiments and spontaneous parametric down-conversion
- The role of imperfections, decoherence, and their effect on the Bloch sphere

5. Quantum communication

- Classical vs. quantum cryptography
- Key distribution protocols: BB84, B89, E91
- Quantum teleportation
- Locality and Bell inequalities

Evaluation

The evaluation of QOT consists of three parts:
1) Two written exams. Overall, they represent 65% of the final mark.
2) There will be assigned problems during the course, to be done at home and delivered to the professor (20% of the final mark).
3) A practical implementation of quantum algorithms using real quantum devices (15% of the final mark).

References

- Nielsen, M.A.; Chuang, I.L. Quantum computation and quantum information. 10th ed. Cambridge, UK: Cambridge University Press, 2010. ISBN 9781107002173.
- Mermin, N. D. Quantum computer science: an Introduction. Cambridge: Cambridge University Press, 2007. ISBN 9780521876582.
- Preskill, J.. "Lecture Notes for Physics 229. Quantum Information and Computation". Caltech University [on line]. Online [Consultation: 01/05/2025]. Available on: https://www.preskill.caltech.edu/ph229/.