Course guide
230483 - QOT - Quantum Optical Technologies

Last modified: 13/06/2024

Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 739 - TSC - Department of Signal Theory and Communications.
748 - FIS - Department of Physics.

Degree: BACHELOR'S DEGREE IN ENGINEERING PHYSICS (Syllabus 2011). (Optional subject).

Academic year: 2024 **ECTS Credits:** 6.0 **Languages:** English

LECTURER

Coordinating lecturer: Consultar aquí / See here:
https://telecos.upc.edu/ca/estudis/curs-actual/professorat-responsables-coordinadors/responsables-assignatura

Others: Consultar aquí / See here:
https://telecos.upc.edu/ca/estudis/curs-actual/professorat-responsables-coordinadors/professorat-assignat-idioma

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
4. Knowledge and understanding of the interaction between radiation and matter in photonic systems. Knowledge of photonic devices and ability for using them. Knowledge of applications in nanotechnology, materials science, communications and biophysics.
5. Knowledge of the structure of matter and its properties at molecular and atomic level. Ability to analyze the behavior of materials, electronics and biophysical systems, and the interaction between radiation and matter.

Generical:
3. ABILITY TO IDENTIFY, FORMULATE, AND SOLVE PHYSICAL ENGINEERING PROBLEMS. Planning and solving physical engineering problems with initiative, making decisions and with creativity. Developing methods of analysis and problem solving in a systematic and creative way.

Transversal:
1. THIRD LANGUAGE. Learning a third language, preferably English, to a degree of oral and written fluency that fits in with the future needs of the graduates of each course.
2. SELF-DIRECTED LEARNING - Level 3. Applying the knowledge gained in completing a task according to its relevance and importance. Deciding how to carry out a task, the amount of time to be devoted to it and the most suitable information sources.

TEACHING METHODOLOGY

Two classes per week (2.5 + 2 hours) from September to December (25 classes). The first part of the course is devoted to fundamental aspects of quantum information and quantum optics (chapters 1 to 4, 13 classes during September and October). The second part of the course is devoted to quantum computing and quantum algorithms (chapter 5 to 7, classes during November and December). The instructor of the first part is Juan P. Torres (juan.perez@upc.edu), and the instructor of the second part is Santiago Torres (santiago.torres@upc.edu).

LEARNING OBJECTIVES OF THE SUBJECT

1) Understanding how quantum theory should be used to solve a diverse variety of problems
2) Understanding basic concepts of quantum theory, its role and importance in the theory, and how to use them: states, operators, orthogonality of states
3) Understanding main quantum technologies: quantum cryptography, entanglement, quantum computing

STUDY LOAD

Type	Hours	Percentage
Hours large group	65,0	43.33
Self study	85,0	56.67

Total learning time: 150 h

CONTENTS

1. Quantum description of light

Description:
Quantization of the electromagnetic field. Modes and excitations: What is a photon?. Revisiting the fundamental principles of quantum theory. Quantum states of light. Quantum description of atoms.

Full-or-part-time: 18h
Theory classes: 4h
Practical classes: 2h
Self study : 12h

2. Quantum superposition, quantum coherence, quantum interference

Description:
Coherent superpositions vs incoherent superpositions. Which-way information. Decoherence. The Hong-Ou-Mandel effect.

Full-or-part-time: 12h
Theory classes: 2h
Practical classes: 2h
Self study : 8h

3. Entanglement and correlations

Description:
What is entanglement? Quantifying and measuring entanglement. How to generate entanglement in the lab: spontaneous parametric down-conversion (SPDC). Bell's inequalities. Locality and realism.

Full-or-part-time: 24h
Theory classes: 5h
Practical classes: 3h
Self study : 16h

4. Quantum Information

Description:
What is quantum information? Quantum processes. How different are two quantum states? Conservation of quantum information (no-cloning theorem).

Full-or-part-time: 24h
Theory classes: 5h
Practical classes: 3h
Self study : 16h

5. Quantum Computing

Description:
5.1 Introduction. What classical/quantum computers can and cannot do. P and NP problems.
5.2 Quantum Circuits Basic Elements.
5.2.1 Operators and quantum gates.
- Universal Basis. Pauli's matrices. Bloch sphere and Rotational matrices
- 2-qubit gates: quantum c-not, crossover, c-u gates
- 3-qubit gates: c-swap, ccnot gate, etc
5.2.2 Quantum measurements.
- Measurement operators. Basis-state, projection and POVM measurements
5.2.3 Quantum Circuits.
- Notation and Basic Examples: superdense coding, teleportation, teleportation of a CNOT.

Full-or-part-time: 30h
Theory classes: 7h
Practical classes: 4h
Self study : 19h

6. Quantum algorithms

Description:
6.1 Quantum Parallelism. An academic example: The Deutsch algorithm
6.2 Shor's algorithm: breaking RSA
6.3 Grover's algorithm: faster searching database

Full-or-part-time: 30h
Theory classes: 7h
Practical classes: 4h
Self study : 19h

7. Quantum Processors

Description:
7.1 What is a universal quantum computer? DiVincenzo criteria.
7.2 State-of-the art: Is there any universal quantum computer?
7.3 Quantum supremacy and quantum advantage: a race to the future.
7.4 IBM-Q and Qiskit, a new standard in quantum computing

Specific objectives:

Full-or-part-time: 12h
Theory classes: 2h
Guided activities: 3h
Self study : 7h

GRADING SYSTEM

The evaluation of QOT consists of three parts:
1) Two exams during the course. The first exam covers chapters 1 to 4, the second exam covers chapters 5 to 7. Each exam represents 30% of the final mark.
2) There will be assigned problems during the course, to be done at home and delivered to the professor (10% of the final mark).
3) As final project, students will be requested to write a report about a subject previously assigned to them. The report may be about a topic not explicitly covered during the course. It might happen that students are requested to make a brief presentation in public of their reports, or make a short video summarizing the content of their reports (30% of the final mark).

BIBLIOGRAPHY

Basic:
- Susskind, L. Quantum mechanics: the theoretical minimum. Basic Books, 2014. ISBN 978-0465036677.
- Gerry, C.; Knight, P. Introductory quantum optics. Cambridge: Cambridge University Press, 2005. ISBN 052152735X.
- 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.

Complementary:
- Scarani, V. Quantum Physics: a first encounter: interference, entanglement and reality [on line]. Oxford: Oxford University Press, 2006 [Consultation: 04/02/2021]. Available on: https://ebookcentral-proquest-com.recursos.biblioteca.upc.edu/lib/upcatalunya-ebooks/detail.action?docID=422472. ISBN 9780198570479.
- Christopher, C. G.; Bruno, K.M. The quantum divide: why Schrodinger cat is either dead or alive. Oxford University Press, 2013. ISBN 9780199666560.
- Cox, B.; Forshaw, J. The Quantum Universe: Everything that Can Happen Does Happen. Da Capo Press, 2013. ISBN 9780306821448.