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230483 - QOT - Quantum Optical Technologies

Coordinating unit: 230 - ETSETB - Barcelona School of Telecommunications Engineering

Teaching unit: 739 - TSC - Department of Signal Theory and Communications
748 - FIS - Department of Physics

Academic year: 2019

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

ECTS credits: 6 Teaching languages: English

Teaching staff

Coordinator: JUAN PEREZ TORRES

Others: SANTIAGO TORRES GIL

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

Three or two classes of two hours per week (changing between two and three classes every week).

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

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Study load

Total learning time: 150h	Hours large group:	65h	43.33%
	Self study:	85h	56.67%

Content

1. Introduction	Learning time: 11h Theory classes: 5h Self study : 6h

Description:
1.1 Goals: why this course
1.2 Learning Quantum ideas
1.3 Quantum Theory: The language of physics
1.4 Overview (review) of algebra of matrix

2. Basic principles of Quantum Theory revisited	Learning time: 19h Theory classes: 4h Practical classes: 4h Self study : 11h

Description:
2.1 The quantum description of a system: states and operators
2.2 Quantum optics: Photons, electrons, atoms
2.3 Different types of states: Coherent, thermal, one and two-photon states
2.4 Information and interference, distinguishability and orthogonality
2.5 Cloning in quantum theory: the No-cloning theorem
2.6 Quantum Cryptography I: the Bennett-Brassard (BB84) protocol

3. Entanglement and some applications: Teleportation and Quantum Cryptography	Learning time: 28h Theory classes: 6h Practical classes: 6h Self study : 16h

Description:
3.1 Entangled states: Quantum correlations and its measurement
3.2 Entanglement in polarization as example. Entanglement in other scenarios
3.3 Experimental implementations: entanglement in-the-lab and out-of-the-lab
3.4 Teleportation
3.5 Quantum Cryptography II: the Ekert-91 Quantum key Distribution (QKD) protocol

4. Fundamental test of how Nature works	Learning time: 19h Theory classes: 4h Practical classes: 4h Self study : 11h

Description:
4.1 Bell?s inequalities and its meaning
4.2 Experimental implementations of the Bell?s inequalities
4.3 Greenberger-Horne-Zeilinger (GHZ) states

5. Decoherence: implications for the implementation of quantum technologies	Learning time: 16h Theory classes: 2h Practical classes: 4h Self study : 10h

Description:
5.1 Decoherence: the appearance of the classical world. Examples
5.2 Schrodinger-cat states
5.3 Implications for the implementation of Quantum Technologies
5.4 Experiments

6. Quantum Computing	Learning time: 57h Theory classes: 18h Practical classes: 6h Guided activities: 3h Self study : 30h

Description:
6.1 Introduction. What classical/quantum computers can and cannot do. P and NP problems.
6.2 Quantum Circuits Basic Elements.
6.2.1 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
6.2.2 Quantum measurements.
-Measurement operators. Basis-state, projection and POVM measurements
6.2.3 Quantum Circuits.
-Notation and Basic Examples: superdense coding, teleportation, teleportation of a CNOT.
6.3 Quantum algorithms
6.3.1 Quantum parallelism. An academic example: the Deutsch's algorithm
6.3.2 Shor's algorithm: breaking RSA.
6.3.3 Grover's algorithm: faster searching database
6.4 Quantum Processors
6.4.1 What is a quantum computer? DiVincenzo criteria. Is D-Wave really the first QC?
6.4.2 Optical Quantum Computer
6.4.3 Ion-trap Quantum Computer
6.4.4 Nuclear Magnetic Resonance Quantum Computer.

Qualification system

Three exams during the semester. Each one represents 30% of the final mark. There is the possibility of recovering the first exam in the final one.
Three assigned problems during the course that should be delivered to the professor (10% of the mark).
A written report about a subject previously assigned, and brief public presentation in class of the main results (30% of the final mark).

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Bibliography

Basic:

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Mermin, N. D. Quantum computer science: an Introduction. Cambridge: Cambridge University Press, 2007. ISBN 9780521876582.

Susskind, L. Quantum mechanics: the theoretical minimum. Basic Books, 2014. ISBN 978-0465036677.

Gerry, C.; Knight, P. Introductory quantum qptics. Cambridge: Cambridge University Press, 2005. ISBN 052152735X.

Peres, A. Quantum theory: concepts and methods [on line]. New York: Kluwer Academic Publishers, 2002 [Consultation: 10/03/2015]. Available on: <http://link.springer.com/book/10.1007/0-306-47120-5>. ISBN 0792336321.

Feynman, R.P.; Leighton, R.B.; Sands, M. The Feynman lectures on physics: vol. 3: quantum mechanics. New millennium ed. New York: Basic Books, 2010. ISBN 9780465024179 (V. 3).

Cohen-Tannoudji, C.; Diu, B.; Laloë, F. Quantum mechanics. Singapore : Paris: Wiley-VCH ; Hermann, 2005. ISBN 9780471569527.

Nielsen, M.A.; Chuang, I.L. Quantum computation and quantum information. 10th ed. Cambridge, UK: Cambridge University Press, 2010. ISBN 9781107002173.

Complementary:

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.

Scarani, V.; Lynn, Ch,; Yang, L.S. Six quantum pieces: a first course in quantum physics. World Scientific Publishing Company, 2010. ISBN 9780521899420.

Aaronson, A. Quantum computing since democritus. Cambridge University Press, 2013. ISBN 9780521199568.

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