Course guide
230483 - QOT - Quantum Optical Technologies

Last modified: 25/05/2023

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: 2023 **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 of two hours each from September to November (chapters 1 to 10). Three classes every week from the last week of November until the end of the course in December (chapter 11).

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

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

Total learning time: 150 h

CONTENTS

1. Quantization of the electromagnetic field

Description:
1.1 Quantization
1.2 Modes and excitations: the photon.
1.3 Quantum states of light

Full-or-part-time: 11h
Theory classes: 5h
Self study : 6h

2. Quantum interference and quantum superposition.

Description:
2.1 Quantum interference vs Classical interference
2.2 Examples

Full-or-part-time: 28h
Theory classes: 6h
Practical classes: 6h
Self study : 16h

3. Entanglement

Description:
3.1 What it is and how to quantify it
3.2 Bell-states and Bell state analyzers
3.3 The quantum channel: Super-dense coding
3.4 Beyond entanglement in polarization

Full-or-part-time: 19h
Theory classes: 4h
Practical classes: 4h
Self study : 11h

4. Parametric down-conversion

Description:
4.1 Parametric down-conversion
4.2 Experiments

Full-or-part-time: 16h
Theory classes: 2h
Practical classes: 4h
Self study : 10h

5. Quantum Teleportation

Description:
1. The protocol of quantum teleportation
2. Importance of quantum teleportation in quantum networks
3. Review of some experimental implementations

Related competencies :
08 CRPE EF. 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.

FOT1. 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.
FQES1. 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.
07 AAT N3. 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.
03 TLG. 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.

Full-or-part-time: 4h
Theory classes: 4h

6. Cloning

Description:
5.1 Superluminal communications with entanglement?
5.2 Impossibility of perfect cloning of quantum information
5.3 A cloning machine: what is the best that we can do

Full-or-part-time: 4h
Theory classes: 4h

7. Quantum cryptography

Description:
7.1 Full security: the one-time pad protocol
7.2 The problem: key distribution
7.3 BB84 and Ekert91

Full-or-part-time: 4h
Theory classes: 4h

8. Quantum sensing

Description:
8.1 Classical and quantum Cramer-Rao bound
8.2 Examples

Specific objectives:

Full-or-part-time: 2h
Theory classes: 2h

9. Correlations, randomness and Bell inequalities

Description:
9.1 Correlations and quantum correlations
9.2 Bell’s inequalities

Full-or-part-time: 4h
Theory classes: 4h

10. Decoherence

Description:
10.1 Why the world looks classical most of the time?
10.2 What is quantumness?

Full-or-part-time: 2h
Theory classes: 2h

11. Quantum Computing

Description:
11.1 Introduction. What classical/quantum computers can and cannot do. P and NP problems.
11.2 Quantum Circuits Basic Elements.
11.2.1 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
11.2.2 Quantum measurements.
- Measurement operators. Basis-state, projection and POVM measurements
11.2.3 Quantum Circuits.
- Notation and Basic Examples: superdense coding, teleportation, teleportation of a CNOT.
11.3 Quantum algorithms
11.3.1 Quantum parallelism. An academic example: the Deutsch's algorithm
11.3.2 Shor's algorithm: breaking RSA.
11.3.3 Grover's algorithm: faster searching database
11.4 Quantum Processors
11.4.1 What is a universal quantum computer? DiVincenzo criteria.
11.4.2 State-of-the art: Is there any universal quantum computer?
11.4.3 Quantum supremacy and quantum advantage: a race to the future.
11.4.4 Nuclear Magnetic Resonance Quantum Computer.

Full-or-part-time: 57h
Theory classes: 18h
Practical classes: 6h
Guided activities: 3h
Self study : 30h

GRADING SYSTEM

The evaluation of QOT consists of three parts:

1) Three exams during the course. The first two exams cover chapters 1 to 10, the third exam covers chapter 11. The two exams covering chapters 1 to 10 will be multiple choice tests. 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, but that the student can do with what has been taught in class. 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:
- Scarani, V.; Lynn, Ch,; Yang, L.S. Six quantum pieces: a first course in quantum physics. World Scientific Publishing Company, 2010. ISBN 9780521899420.
- 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.
- 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.

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. 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.