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.

General:
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
## Study load

<table>
<thead>
<tr>
<th><strong>Total learning time:</strong> 150h</th>
<th>Hours large group: 65h</th>
<th>43.33%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Self study: 85h</td>
<td>56.67%</td>
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</tbody>
</table>

**Total learning time:** 150h
# 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

**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

**Learning time:** 19h
- Theory classes: 4h
- Practical classes: 4h
- Self study: 11h

### 5. Decoherence: implications for the implementation of quantum technologies

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

**Learning time:** 16h
- Theory classes: 2h
- Practical classes: 4h
- Self study: 10h
### 6. Quantum Computing

<table>
<thead>
<tr>
<th>Learning time: 57h</th>
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</thead>
<tbody>
<tr>
<td>Theory classes: 18h</td>
</tr>
<tr>
<td>Practical classes: 6h</td>
</tr>
<tr>
<td>Guided activities: 3h</td>
</tr>
<tr>
<td>Self study: 30h</td>
</tr>
</tbody>
</table>

#### 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).
Bibliography

Basic:


Complementary:


