

**Quantum Optics**

Code: 100180  
ECTS Credits: 6

Degree	Type	Year	Semester
2500097 Physics	OT	4	0

**Contact**

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**Use of languages**

Principal working language: english (eng)  
Some groups entirely in English: Yes  
Some groups entirely in Catalan: No  
Some groups entirely in Spanish: No

**Teachers**

Jordi Mompart Penina

**Prerequisites**

There are no prerequisites. However, it is recommended to have passed Quantum Physics I and II.

**Objectives and Contextualisation**

The aim of this course is to provide students with the fundamental concepts of Quantum Optics. In particular, we will study in detail light-matter interaction at a microscopic level using semiclassical and quantum theory. These two approaches are at the basis of very active research fields such as laser physics, coherent control of matter waves, cooling and trapping of atoms, and quantum information. Throughout the course we will provide connections to all these fields and discuss recent research results.

**Skills**

- Apply fundamental principles to the qualitative and quantitative study of various specific areas in physics
- Be familiar with the bases of certain advanced topics, including current developments on the parameters of physics that one could subsequently develop more fully
- Carry out academic work independently using bibliography (especially in English), databases and through collaboration with other professionals
- Communicate complex information in an effective, clear and concise manner, either orally, in writing or through ICTs, and before both specialist and general publics
- Develop critical thinking and reasoning and know how to communicate effectively both in the first language(s) and others
- Develop independent learning strategies
- Formulate and address physical problems identifying the most relevant principles and using approximations, if necessary, to reach a solution that must be presented, specifying assumptions and approximations

- Generate innovative and competitive proposals for research and professional activities.
- Respect the diversity and plurality of ideas, people and situations
- Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
- Use mathematics to describe the physical world, selecting appropriate tools, building appropriate models, interpreting and comparing results critically with experimentation and observation
- Using appropriate methods, plan and carry out a study or theoretical research and interpret and present the results
- Work independently, have personal initiative and self-organisational skills in achieving results, in planning and in executing a project
- Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

## Learning outcomes

1. Analyse the physics of two and three-level atomic systems interacting with one or two laser fields, respectively.
2. Calculate the dressed states of a two-level system interacting with an electromagnetic field.
3. Calculate the interaction dynamics of a two-level system coupled to a single mode of the electromagnetic field.
4. Carry out a project that relates the concepts of quantum optics studied with current innovative issues and present the results.
5. Communicate complex information in an effective, clear and concise manner, either orally, in writing or through ICTs, in front of both specialist and general publics.
6. Deduce the dipolar force of light and describe the radiation pressure.
7. Describe the Hanbury-Brown and Twiss experiment.
8. Describe the concept of spatial and temporal coherence of light.
9. Describe the phenomenon of spontaneous emission.
10. Describe the techniques for handling the internal and external states of atoms using light-matter interaction and its applications to quantum engineering.
11. Describe the techniques to control light propagation and their applications to quantum memories.
12. Develop critical thinking and reasoning and communicate ideas effectively, both in the mother tongue and in other languages.
13. Develop independent learning strategies.
14. Formulate the properties of different quantum states of the electromagnetic field.
15. Generate innovative and competitive proposals for research and professional activities.
16. Model the cavity quantum electrodynamics
17. Pose and solve the equations for the coherent evolution of a system of two atomic levels interacting with a laser field using the Schrödinger's equation.
18. Respect diversity in ideas, people and situations.
19. Solve problems of light-matter interaction in semiclassical theory using the density matrix technique.
20. Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
21. Use the normal variables to describe the electromagnetic field and its quantisation.
22. Within the electric dipole and rotating wave approximations, calculate the dynamics of two- and three-level systems interacting with a classical or a quantum field.
23. Work independently, take initiative itself, be able to organize to achieve results and to plan and execute a project.
24. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.
25. Carry out academic work independently using bibliography (especially in English), databases and through collaboration with other professionals

## Content

### 1. Introduction

Overview of classical, semiclassical and quantum theories of light-matter interaction. Atomic structure.

## 2. Semiclassical theory of light-matter interaction

Basic processes of light-matter interaction. Einstein's rate equations. Schrödinger equation. Two-level atom under the rotating wave approximation. Selection rules. AC-Stark splitting. Rabi oscillations. Mollow's triplet. Autler-Townes doublet. Light shifts. Dipole force. Density-matrix formalism: two and three-level atoms. Coherent Population Trapping, Electromagnetically Induced Transparency, Stimulated Raman Adiabatic Passage.

## 3. Quantum theory of light-matter interaction

### 3. 1. Light's description

Classical electrodynamics. Quantization of the e.m. field. Quantum states of the free e.m. field. Fock states. Vacuum states. Coherent states. Squeezed states. Optical coherence and Hanbury-Brown and Twiss experiment. Wigner function. Beam splitters and interferometers.

### 3. 2. Light-matter interaction

Jaynes-Cummings model. Dressed atom. Quantum Rabi oscillations. Collapses and revivals. Cavity quantum electrodynamics. Weisskopf-Wigner theory of spontaneous emission.

## Methodology

The subject has assigned 1.8 ECTS classroom teaching: 1.2 ECTS for lectures and 0.6 ECTS for exercises.

In the lectures, the course contents will be discussed in detail always encouraging the students participation by raising questions.

In the exercises classes, it is intended that the students participate actively asking questions and contributing to the resolution of the exercises during the class.

The required autonomous work of the student in this course includes the study of theoretical concepts as well as the preparation and solution of the exercises.

The course also features supervised activities consisting of the delivery of exercises and an oral presentation of a current topic of quantum optics, which will be done in group.

The material for both the lectures and for the exercises classes will be provided through the UAB Virtual Campus of this subject.

## Activities

Title	Hours	ECTS	Learning outcomes
<b>Type: Directed</b>			
Exercises classes	15	0.6	1, 2, 3, 22, 6, 8, 9, 7, 11, 10, 14, 16, 17, 19, 21
Lectures (Theory classes)	30	1.2	1, 2, 3, 22, 6, 8, 9, 7, 11, 10, 14, 16, 17, 19, 21
<b>Type: Supervised</b>			
Deliveries	1.5	0.06	5, 13, 12, 25, 15, 20, 18, 23
Oral presentation	1.5	0.06	5, 13, 12, 4, 25, 15, 20, 18, 23, 24

<b>Type: Autonomous</b>				
Preparation and study of the theory concepts	49	1.96	1, 5, 6, 8, 9, 7, 11, 10, 13, 12, 4, 25, 14, 15, 16, 20, 18, 23, 24, 21	
Solving exercises	47	1.88	2, 3, 22, 5, 13, 12, 4, 25, 15, 17, 20, 19, 18, 23, 24	

## Evaluation

The final mark of the subject will be obtained as follows:

- 35% : Mark of the first partial exam.
- 35% : Mark of the second partial exam.
- 15% : Mark of the activities to deliver.
- 15% : Mark of the oral presentation.

In order to apply these percentages, the mark in each of the partial exams should be equal or above 3,5 from 10. If the mark of one or both partial exams is below 3,5, the student has to do a retaking exam of the part of the subject failed with mark below 3,5. If a student has passed the subject but he/she would like to improve the mark of the written exams, he/she can do a retaking exam and the final mark of the subject will be calculated using the percentages shown above with the mark obtained in the retaking exam. If a student does not attend any of the exams or only attends one of the partial exams, his/her mark will be "No avaluable". In order to be able to attend the retaking exam, the student must have attended the two partial exams.

## Evaluation activities

Title	Weighting	Hours	ECTS	Learning outcomes
Delivery of activities	15%	0	0	5, 13, 12, 4, 25, 15, 20, 18, 23
First partial exam	35%	3	0.12	1, 3, 22, 6, 8, 9, 7, 11, 10, 17, 19
Oral presentation	15%	0	0	5, 13, 12, 25, 15, 20, 18, 23, 24
Retaking exam first partial	35%	0	0	1, 2, 3, 22, 6, 8, 9, 7, 11, 10, 14, 16, 17, 19, 21
Retaking exam second partial	35%	0	0	1, 2, 3, 22, 6, 8, 9, 7, 11, 10, 14, 16, 17, 19, 21
Second partial exam	35%	3	0.12	2, 22, 9, 14, 16, 21

## Bibliography

- **From the web:**

Daniel A. Steck, *Quantum and Atom Optics* (2007)

Oregon Center for Optics and Department of Physics. Oregon University

<http://atomoptics.uoregon.edu/~dsteck/teaching/quantum-optics/quantum-optics-notes.pdf>

- **Basic bibliography**

P. Meystre and M. Sargent, *Elements of Quantum Optics*, Springer-Verlag, 4th edition, 2007.

M. O. Scully and M.S. Zubairy, *Quantum Optics*, Cambridge U. P., 1997.

D. F. Walls and G.J. Milburn, *Quantum Optics*, Springer-Verlag, 2nd edition, 2008.

C. C. Gerry and P. Knight, *Introductory Quantum Optics*, Cambridge University Press, 2005.

- **Advanced bibliography**

C. Cohen-Tannoudji, J. Dupont-Roc and G. Grynberg, *Atom-Photon Interactions: Basic processes and applications*. John Wiley & Sons, 1998.

C. Cohen-Tannoudji, J. Dupont-Roc and G. Grynberg, *Photons and Atoms: Introduction to Quantum Electrodynamics*. John Wiley & Sons, 1997.

H. J. Metcalf and P. van der Straten, *Laser Cooling and Trapping*, Springer-Verlag, 1999.

S. Haroche and J.M. Raimond. *Exploring the Quantum: Atoms, Cavities and Photons*. Oxford University Press, 2006.

J. M. Raimond, M. Brune and S. Haroche, *Reviews of Modern Physics* 73, 565 (2001).