COURSE DATA

Data Subject	
Code	34276
Name	Quantum optics
Cycle	Grade
ECTS Credits	6.0
Academic year	2021 - 2022

Study (s)

Degree	Center	Acad. year	Period
1105 - Degree in Physics	Faculty of Physics	4	Second term

Subject-matter

Degree	Subject-matter	Character
1105 - Degree in Physics	16 - Complements of Physics	Optional

Coordination

Name	Department
ROLDAN SERRANO, EUGENIO	280 - Optics and Optometry and Vision Sciences
VALCARCEL GONZALVO, GERMAN JOSE DE	280 - Optics and Optometry and Vision Sciences

SUMMARY

Descriptors: Quantum theory of light, photons, coherent states, squeezed light, non-classical light, light-atom interaction, photodetection, theory of laser.

Objectives: This course aims for students to achieve a basic understanding of the quantum nature of light and the interaction of this (in the optical domain of the electromagnetic spectrum, which excludes frequencies above and below the X-rays to microwaves) with matter, mainly with atoms and molecules. After quantifying the field, we study the coherent states of the electromagnetic field and discusses their properties. Discussed below are the basic processes of interaction (spontaneous emission, stimulated emission and absorption). Afterthe study photodetection (capitally essential to understand the quantum nature of light), paying particular attention to the so-called «non-classical states» of radiation, such as compressed states (squeezed states), studying how they can be generated. It also addresses an introduction to quantum entanglement and its implications for quantum optics.

Besides all this, is also an aim to understand the fundamental aspects of the semiclassical theory of light-matter interaction (in which the field is treated classically) with the intention of obtaining the fundamental equations of semiclassical laser theory (equations Maxwell-Bloch). Studies of this phenomena include nonlinear dynamics of lasers inthe emission (such as deterministic chaos) which are transverse interest.

Relation to previous courses: Quantum optics is based on the compulsory courses in optics, electromagnetism and quantum mechanics. The skills taught in this course have not been treated in any other head, except the lens, which is the theory of laser-balance equations of Einstein and quantum mechanics, which is (partially) some aspects which are developed further in quantum optics.

PREVIOUS KNOWLEDGE

Relationship to other subjects of the same degree

There are no specified enrollment restrictions with other subjects of the curriculum.

Other requirements

it would be required a basic knowledge of classical electromagnetism, quantum mechanics and classical optics. All these skills are acquired studying the corresponding subjects of the degree in physics.

OUTCOMES

1105 - Degree in Physics

- Knowledge and understanding of the fundamentals of physics in theoretical and experimental aspects, and the mathematical background needed for its formulation.
- To know how to apply the knowledge acquired to professional activity, to know how to solve problems and develop and defend arguments, relying on this knowledge.
- Ability to collect and interpret relevant data in order to make judgements.
- Problem solving: be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems .
- Modelling & Problem solving skills: be able to identify the essentials of a process / situation and to set up a working model of the same; be able to perform the required approximations so as to reduce a problem to an approachable one. Critical thinking to construct physical models.
- Physics general culture: Be familiar with the most important areas of physics and with those approaches which span many areas in physics, or connections of physics with other sciences.
- Basic & applied Research: acquire an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, e.g. engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results.

- Foreign Language skills: Have improved command of English (or other foreign languages of interest) through: use of the basic literature, written and oral communication (scientific and technical English), participation in courses, study abroad via exchange programmes, and recognition of credits at foreign universities or research centres.
- Literature Search: be able to search for and use physical and other technical literature, as well as any other sources of information relevant to research work and technical project development.
- Learning ability: be able to enter new fields through independent study, in physics and science and technology in general.
- Communication Skills (written and oral): Being able to communicate information, ideas, problems and solutions through argumentation and reasoning which are characteristic of the scientific activity, using basic concepts and tools of physics.
- Students must have acquired knowledge and understanding in a specific field of study, on the basis of general secondary education and at a level that includes mainly knowledge drawn from advanced textbooks, but also some cutting-edge knowledge in their field of study.
- Students must be able to apply their knowledge to their work or vocation in a professional manner and have acquired the competences required for the preparation and defence of arguments and for problem solving in their field of study.
- Students must have the ability to gather and interpret relevant data (usually in their field of study) to make judgements that take relevant social, scientific or ethical issues into consideration.
- Students must be able to communicate information, ideas, problems and solutions to both expert and lay audiences.
- Students must have developed the learning skills needed to undertake further study with a high degree of autonomy.

LEARNING OUTCOMES

Acquire a basic knowledge of:

- The quantum nature of light.
- The interaction of light with matter, especially with atoms and molecules.

In particular:

- The nonrelativistic quantització́n light.
- The variety of states of light and to distinguish the quantum characteristics of the classic.
- The basic processes of interaction (absorption and emission).
- The process of photodetection and its application to the characterization of states.
- What is quantum entanglement and its usefulness.
- The foundations of the semiclassical theory of light-atom interaction and its application to laser.
- The basics of nonlinear dynamics of the laser.

In addition, the properties of the degree:

- Ability to understand and synthesize the issues raised in order to reach a solution.
- Ability to work in an organized manner. Establish work plans which can achieve the desired results more directly.
- Skill in seeking information from the literature.
- Interpretation of graphs.
- Ability to work in groups.
- Use of new technologies.
- Ability to develop texts and reports on the work carried out in an understandable and organized.
- Rigor when assessing the work of the same. Being able to identify the causes of errors and possible solutions.
- Ability to identify and assess the importance of scientific concepts convoluted with their applications to other fields of science and improved social welfare.
- Ability to scientific communication, both oral and written, in academia and the informative.
- Ability to argue from rational and scientific criteria, both academic and informative, avoiding prejudice.
- Attitudes and values that set the conditions to develop ethical behavior in the development of professional activity.

DESCRIPTION OF CONTENTS

1. Semiclassical theory of light-matter interaction

1. Introduction. The two-level atom
2. Interaction Hamiltonian
3. Evolution equations. The rotating-wave approximation
4. Rabi oscillations
5. The dressed atom
6. Pulses
7. Dissipation. The density matrix. Optical Bloch equations
8. The refractive index
9. Three-level atoms. Two-photon, Raman and hyper-Raman processes

Seminars: Semiclassical laser theory
1. The ring cavity two-level laser
2. Amplification in a two-level medium
3. The laser: single-mode emission
4. The Lorenz-Haken model
5. Linear stability analysis
6. Spontaneous pulsations and routes to chaos

2. Quantization of the free electromagnetic field

1. Canonical quantization of a harmonic oscillator. Creation and annihilation operators
2. The free em field: potentials and gauge invariance
3. The standard em field Lagrangian. Scheme for the standard quantization
4. Canonical quantization of a mode in a Fabry-Perot resonator
5. Free em field Hamiltonian
5. Electric and magnetic fields operators. Linear and angular momentum operators
6. Time evolution pictures

3. Photons and the quantum vacuum

1. Number or Fock states: photons
2. The electric field in a Fock state
3. The em vacuum. Quantum fluctuations
4. The Casimir effect

4. Coherent states

1. Quasi-classical states of the electromagnetic field
2. Expansion of coherent states in the Fock basis
3. The displacement operator
4. Physical properties of the coherent states
5. Mathematical properties of the coherent states

5. Squeezed states

1. The field quadrature operators
2. Balanced homodyne detection
3. Introduction to quantum squeezing
4. The squeezing operator
5. Parametric down conversion
6. Squeezed states

6. Quantum theory of light-atom interaction

1. Electric-dipole Hamiltonian
2. Elementary processes
3. Spontaneous emission. Weisskopf-Wigner theory
4. Decay. Spontaneous emission within cavities
5. Atomic level energy shift. The Lamb shift.
6. Mass renormalization

7. The Jaynes-Cummings model

1. Introduction. The Rabi model
2. The Jaynes-Cummings model
3. Trapped ion driven by classical light
4. Solving the Schrödinger equation
5. Atomic properties evolution
6. Field properties evolution
7. Experimental observations

8. Quantum coherence and photodetection

1. Introduction
2. Semi-classical theory of photodetection and coherence
3. Quantum theory of photodetection and coherence

9. Entanglement

1. Entangled states
2. Density matrix. Pure and mixed states. Purification
3. Generation of entangled states in optical systems
4. The EPR argument
5. Bells theorem
6. Optical tests of Bells theorem
7. Applications of entangled states

WORKLOAD

ACTIVITY	Hours	% To be attended
Theory classes	60,00	100
	0,00	100
Development of individual work	20,00	0
Study and independent work	45,00	0
Readings supplementary material	5,00	0
Resolution of case studies	20,00	0
TOTAL	**150,00**	

TEACHING METHODOLOGY

This course has two types of classes. The first one corresponds to the theoretical or theoretical-practices in which it is reforced, as much as possible, the participation of students. This is the most common type of class in this subject (52 of the 60 hour period). During these classes the teacher presents an orderly and self-contained (to the extent possible) the contents of the seven chapters of the course.

The second kind of classes corresponds to the seminars and these are subdivided into two: half of the seminars are theoretical (the difference with the recently described classes is that it is not intended to be as complete and self-contained). The aim is that students learn to follow a more relajadalos contents of a portion of matter, especially enhancing intuition and concentrating efforts on the study of net models. The other half of the seminars are practical since in them aprendecomo are built and used the software needed to complete the planned simulations.

EVALUATION

There are two assessment systems:

1. Written exams. The understanding of theoretical, conceptual and formal aspects will be assessed, as well as the ability to apply the formalism to problem solving and the criticism about the results. In any case a correct reasoning and justification will be assessed.
2. Continuous assessment. Based on the execution of homework, memoirs, problem solving and other activities. The output may be delivered through written documents or oral presentations.

The weight of each part is: 60% for the exams and 40% for the continuous assessment.

REFERENCES

Basic

- R. Loudon, The quantum theory of light (Clarendon Press, 1983)
- P. Milonni i J.H. Eberly, Lasers (John Wiley and Sons, 1988)
- Ch.C. Gerry i P.L. Knight, Introductory Quantum Optics (Cambridge University Press, 2005)

Additional

- C. Cohen-Tannoudji, J. Dupont-Roc i G. Grynberg, Photons and atoms. Introduction to Quantum Electrodynamics (John Wiley and Sons, 1989)
-H. Haken, Light (vols. 1 i 2) (North Holland, 1985)
-L. Mandel i E. Wolf, Optical coherence and Quantum Optics (Cambridge University Press, 1995)
-L. Allen and J.H. Eberly, Optical resonance and two-level atoms (Dover, 1987)

-W.H. Louisell, Quantum statistical properties of radiation (Oxford University Press, 2000)
-W. Vogel i D.-G. Welsch, Lectures on quantum optics (Akademie Verlag, 1994).
-M.O. Scully i M.S. Zubairy, Quantum Optics (Cambridge University Press, 1997)

ADDENDUM COVID-19

This addendum will only be activated if the health situation requires so and with the prior agreement of the Governing Council

TEACHING METHODOLOGY:

In case that health situation requires blended teaching, the teaching model approved by the Academic Degree Committee on July 23, 2020 will be adopted.

— Compulsory subjects: 50% student attendance in the classroom, while the rest of students attend the class in streaming broadcast. Two groups will be set with alternate days attendance to the classroom in order to guarantee 50% of teaching hours attendance for all students. Laboratory sessions will have a 100% attendance.

— Optional subjects: 100% attendance in all activities.

If a total reduction in attendance is necessary, classes will be broadcast by synchronous videoconference at their regular schedule, along the period determined by the Health Authority.