1. OVERVIEW

Subject area	Quantum Physics II
Degree	Bachelor's Degree in Physics
School/Faculty	School of Architecture, Engineering and Design
Year	Fourth
ECTS	6 ECTS
Type	Compulsory
Language(s)	Spanish
Delivery mode	On campus
Semester	First semester

2. INTRODUCTION

This subject area, the natural continuation of Quantum Physics I, provides the remaining knowledge about non-relativistic quantum mechanics that students will need to move into specialist fields such as quantum computing, molecular physics, condensed matter, quantum optics and nuclear and particle physics, among others.

It completes the essential study of quantum physics by introducing the following concepts: the general definition of angular momentum and the addition of angular momenta (which is not as simple as the addition of classical angular momenta), with a special focus on the addition of orbital angular momenta and spin angular momenta; the use of wave functions to describe the statistical behaviour of bosons and fermions; the simplest methods of approximation to solve the Schrödinger equation; and the most basic quantum theory of dispersion.

3. SKILLS AND LEARNING OUTCOMES

General skills (CG, by the acronym in Spanish):

- CG1. To understand key concepts, methods and findings in the different branches of physics while gaining a historical perspective of their development.
- CG5. To understand diverse phenomena that, despite being physically different, share certain similarities, allowing known solutions to be applied to new problems.

Key skills (CB, by the acronym in Spanish):

- CB4. Students can communicate information, ideas, problems and solutions to both specialist and non-specialist audiences.

Transversal skills (CT, by the acronym in Spanish):

- CT5. Problem solving: Be able to critically evaluate information, separate complex situations into their constituent parts, recognise patterns, and consider alternatives, different approaches and perspectives in order to find optimal solutions and negotiate efficiently.

- CT6. Adaptability: Being able to accept, appreciate and integrate different positions, being able to adapt one's own approach as required by the situation, as well as working effectively in ambiguous situations.

Specific skills (CE, by the acronym in Spanish):

- CE02. To describe and analyse physical systems, identifying fundamental concepts and principles to make the approximations needed to build a simplified model.
- CE03. To understand the inherent limitations of classical physics that led to the emergence of the general and special theories of relativity and quantum mechanics, resulting in solutions to new physics problems.
- CE04. To understand the laws and principles of physics, to identify their logical and mathematical structure, their experimental basis and the phenomena described through them.

Learning outcomes (RA, by the acronym in Spanish):

- RA1. To understand the problem of indistinguishability in quantum mechanics and its impact on the study of systems with lots of identical particles.
- RA2. To use approximation methods to analyse quantum systems that cannot be resolved in a more precise manner.
- RA3. To apply collision theory in quantum mechanics in simple dispersion models.

The following table shows how the skills developed in the subject area match up with the intended learning outcomes:

Skills	Learning outcomes
CG1, CG5, CB4, CT5, CE02, CE03, CE04.	**RA1**. To understand the problem of indistinguishability in quantum mechanics and its impact on the study of systems with lots of identical particles.
CG1, CG5, CB4, CT5, CT6, CE02, CE03, CE04.	**RA2.** To use approximation methods to analyse quantum systems that cannot be resolved in a more precise manner.
CG1, CB4, CT5, CE02, CE03, CE04.	**RA3.** To apply collision theory in quantum mechanics in simple dispersion models.

4. CONTENTS

This subject is organised into learning units.

Unit 1. General angular momentum.

- 1.1. General definition, eigenvalues, scalar operators.
- 1.2. Matrix representation. 1.3. Addition.

Unit 2. Spin angular momentum.

- 2.1. Stern–Gerlach experiment and electron spin. 2.2. Precession in the presence of a magnetic field.

Unit 3. Systems of identical particles.

- 3.1. Permutations and the symmetrization postulate.
- 3.2. Bosons and fermions.
- 3.3. Bose gas, Fermi gas, other cases.

Unit 4. Approximation methods.

- 4.1. Stationary perturbation theory for degenerate and non-degenerate levels.

- 4.2. Variational method.
- 4.3. Time-dependent perturbation.

Unit 5. Introduction to the quantum theory of dispersion.
- 5.1. Scattering amplitude, cross section.
- 5.2. Time-independent description. Born approximation.

5. TEACHING/LEARNING METHODS

The types of teaching/learning methods are as follows:

- Collaborative learning: Students learn to collaborate with other people (classmates and professors) in order to find creative, comprehensive and constructive solutions to questions and problems that arise from the given case studies, using all relevant knowledge and material resources available.
- Problem-based learning: Students are given problems and asked to solve them, working individually or in groups.
- Lectures: Presentations by the professor with the necessary technological tools to maximise comprehension of the learning content.
- Guided academic activities: Individual and group work that is more independent, including information searches, written summaries, debates and the public defence of projects.

6. LEARNING ACTIVITIES

The types of learning activities, plus the amount of time spent on each activity, are as follows:

On campus:

Learning activity	Number of hours
Lectures	33
Asynchronous lectures	12
Report writing	13.5
Assessment	6
Practical activities (problems, written work, projects, workshops and/or lab work)	21
Group tutorials	10
Independent working	54.5
TOTAL	**150**

7. ASSESSMENT

The assessment systems, plus their weighting in the final grade for the subject area, are as follows:

On campus:

Assessment system	Weighting
Individual on-campus knowledge tests (theory and/or practice)	50%
Oral defence	5%
Submission of group and/or individual reports, written work, projects or exercises	30%
Performance observation	15%

On the Virtual Campus, when you open the subject area, you'll find details of your assessable tasks, including the submission dates and assessment procedures for each task.

8. BIBLIOGRAPHY

The reference material for the subject area is as follows:

- Sánchez del Río, C. (2020). *Física Cuántica*. Editorial Pirámide. Madrid.
- Griffiths, David. G. y Schroeter, Darrell F. (2018). *Introduction to Quantum Mechanics*. Editorial Cambridge University Press.

The recommended bibliography is indicated below:

- Cohen-Tannoudji, C. et al. (2019). *Quantum Mechanics.* Volúmenes I y II. Editorial Wiley.