COURSE DATA

Data Subject	
Code	34271
Name	Advanced quantum mechanics
Cycle	Grade
ECTS Credits	6.0
Academic year	2022 - 2023

Study (s)

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

Subject-matter

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

Coordination

Name	Department
MOLINA PERALTA, RAQUEL	185 - Theoretical Physics

SUMMARY

This optional subject serves as a complement to Quantum Mechanics, a compulsory fourth-year subject in the Bachelor’s degree in Physics at the University of Valencia. Regarding its specific content, it begins with a brief review of Hilbert spaces before the introduction of the concept of symmetry in quantum mechanics. Continuous (translations, rotations) and discrete (parity, time reversal) symmetries are considered. Next, the theory of scattering is developed, introducing the concept of effective section in quantum mechanics; Born's approximation is studied. The behavior of non-relativistic charged particles in external electromagnetic fields is analyzed, and finally an introduction to quantum computing is provided.

Relationship with previous subjects: The subject is proposed as a continuation of the 4th year Quantum Mechanics subject which, in turn, complements the 3rd year Quantum Physics I and II courses. Apart from this relationship, it is worth mentioning its formal relationship with the subject of Classical Mechanics. Also of great importance is the mathematical background acquired in Mathematical Methods on vector spaces, matrix algebra and diagonalization.

Relationship with subsequent subjects: There are many Physics subjects that use the knowledge of Quantum Mechanics and Advanced Quantum Mechanics: Solid State, Quantum Optics, Nuclear and Particle Physics and Quantum Field Theory.

PREVIOUS KNOWLEDGE

Relationship to other subjects of the same degree

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

Other requirements

Mathematics

1. Hibert spaces.
3. Linear operators: Hermitian and unitary operators.
4. Matrices and determinants.
5. Diagonalization of linear operators and matrices.
6. Fourier transform.
7. Dirac delta.

Physics

1. Postulates of Quantum Mechanics.
2. Symmetries in Classical Mechanics.
3. Classical Scattering theory.
4. Charged classical particle in an electromagnetic field.

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

• Understand the concept of symmetry in Quantum Mechanics, its mathematical implementation and the derived conservation laws. Application to physical problems.

• Understand the underlying physical ideas in the formulation of the quantum theory of scattering. Comparison with classical theory.

• Learn the behavior of a non-relativistic particle in an external electromagnetic field. Possible extensions of the formalism.

• Understand the basic concepts of quantum computing.

DESCRIPTION OF CONTENTS

1. Preliminary questions and notation

Hilbert space. Properties.
Observables and measures
Wave functions
Schrödinger equation
Born's rule
Expected value
Commutation relations
Review of the postulates of quantum mechanics

2. Symmetries in quantum mechanics

Symmetries in quantum mechanics
Wigner's theorem
Symmetry Transformations Group
Continuous Symmetries
Discrete symmetries

3. Translations and rotations

Spatial translations
Generators of Spatial Translations
Spatial Translation for a Particle System
Velocity translations
Rotations in quantum mechanics
Spin 1/2 systems
Interferometry of neutrons and rotations of angle 2
Representations of the operator of rotations and Euler angles
Composition of angular momentum and Clebsch-Gordan coefficients
Tensor operators
Cartesian tensor operators and spherical tensor operators (or irreducible)
Wigner-Eckart theorem

4. Discrete symmetries

Parity
Transformation of states and operators
Eigenstates of parity
Transformation of wave functions
Conservation laws
Parity of a particle system
Intrinsic Parity Assignment
Parity Violation
Selection rules
Temporary investment
C-Parity
CPT theorem
Isospin
Two nucleon system
Isospin multiplets
Pions

5. Symmetries of identical particles

Identical particles
Bosons and fermions
Pauli Exclusion Principle
Separable hamiltonian
System of two identical particles. The helium atom

6. Scattering theory

Scattering amplitude
Cross section
Laboratory reference systems and center of mass
Optical theorem
Born approximation
Core Potential
Asymptotic behavior of the wave function
Phase shifts and amplitude development in partial waves
Argand diagram
Development of the cross section in partial waves
Resonances
Charged Particle in an External Electromagnetic Field
Gauge Symmetry

7. Introduction to quantum computing

Introduction
Bits and Qubits
Entanglement
Bell's inequalities
Entropy
One-qubit gates
Multi-qubit gates
Non-cloning theorem
Quantum algorithms
Grover's algorithm
Teleportation
Quantum Eraser
Quantum cryptography

WORKLOAD

ACTIVITY	Hours	% To be attended
Theory classes	60,00	100
	0,00	100
Development of individual work	20,00	0
Preparation of evaluation activities	20,00	0
Preparing lectures	25,00	0
Preparation of practical classes and problem	25,00	0
TOTAL	**150,00**	

TEACHING METHODOLOGY

Theoretical classes: Three hours per week during the school period. The theoretical classes will be, in general, of a magisterial nature and in them the contents of the subject will be exposed. Special emphasis will be placed on the application of theoretical knowledge to the solution of issues and problems. Simple physical systems will be solved as an example of the general theoretical methods studied and the results will be compared with the experimental data.

Practical classes: One hour per week during the school period. In the practical classes, problems of each topic of the subject will be solved. The teacher will previously give the students a collection of problems for each topic. The students will expose the work carried out on these problems during the practical class.

EVALUATION

1. Written exams: the understanding of the conceptual aspects of the subject, theability to apply the formalism developed as well as the critical analysis of the resultsobtained. The exam will consist of questions and problems.

2. The mark of the exams will be weighted with the mark of the continuous evaluation that will consist of the resolution of problems. The final grade will be the maximum grade between the exam grade and the weighted average = 0.75*Exam grade + 0.25*Continuous evaluation.

REFERENCES

Basic

- Mecánica Cuántica. A. Galindo, P. Pascual. Alhambra o Eudema Universidad.
- Lectures on Quantum Mechanics. S. Weinberg. Cambridge University Press.
- Quantum Mechanics, Vol. I, II. C. Cohen-Tannoudji, B. Diu, F. Laloë. Wiley.
- Problems in Quantum Mechanics: With Solutions. G. L. Squires. Cambridge University Press.
- Quantum Computation and Quantum Information. M.A. Nielsen y I.L. Chuang. Cambridge University Press.

Additional

- Modern Quantum Mechanics. J. J. Sakurai. Addison-Wesley.
- Problems in Quantum Mechanics. F. Constantinescu, E. Magyani. Pergamon