Universitat Autònoma de Barcelona

2023/2024

Advanced Quantum Mechanics

Code: 100178
ECTS Credits: 6

Degree	Type	Year	Semester
2500097 Physics	OT	4	2

Contact

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Teaching groups languages

You can check it through this link. To consult the language you will need to enter the CODE of the subject. Please note that this information is provisional until 30 November 2023.

Prerequisites

Recommendation: Quantum physics. Quantum mechanics and theoretical mechanics.

Objectives and Contextualisation

Introduce the most basic concepts (conceptual and mathematical) of quantum field theory. Special emphasis is placed on the connection with non-relativistic quantum mechanics, as well as with classical field theory. In addition, the student must acquire the ability to apply calculation tools with agility to different types of problems.

Competences

- 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
- 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
- Make changes to methods and processes in the area of knowledge in order to provide innovative responses to society's needs and demands.
- Take account of social, economic and environmental impacts when operating within one's own area of knowledge.

- 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 consequences of Dirac's equation on the nonrelativistic limit.
2. Analyse the limits of simple high and low energy electromagnetic processes.
3. Apply gauge invariance for the Lagrangian determination of quantum electrodynamics.
4. Calculate cross sections for simple electromagnetic processes.
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. Establish the bases for the comprehensive formulation of quantum field theory and its applications.
7. Establish the phenomenological consequences of relativistic wave equations.
8. From a specific initial and final state, structure and develop the strategy and calculation for the cross section of an electromagnetic process.
9. Identify situations in which a change or improvement is needed.
10. Identify the social, economic and environmental implications of academic and professional activities within one's own area of knowledge.
11. Obtain irreducible representations of the Poincaré group and apply them to particle states.
12. Obtain transitional amplitudes for electromagnetic processes using Feynman's rules.
13. Study collisions with identical particles.
14. Use Noethers theorem in quantum field theories.
15. Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
16. Use phase-space integration correctly.
17. Work independently, take initiative itself, be able to organize to achieve results and to plan and execute a project.
18. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.
19. Carry out academic work independently using bibliography (especially in English), databases and through collaboration with other professionals

Content

1. General motivation

2. Introduction (classical fields)

(a) Motivation for fields: Many body problems. One example

(b) Elements of classical field theory:

• Functional calculus (reminder)
• Lagrangian and Hamiltonian formalism. Euler-Lagrange equations
•Noether theorem (later (5.d))

(c) Natural units

3. Non-relativistic Quantum FieldTheory. Free fields

(a) Bosons. Fock space. Number operator (particle interpretation) and statistics. Connection with quantum mechanics

(b) Fermions. Fock space. Number operator (particle interpretation) and statistics. Connection with quantum mechanics

4. Poincare Group

(a) Poincare group and Lorentz group.

(b) Associated Lie algebra.

(c) One particle irreducible representation. Wigner method. Little group. Spin, helicity. Massive and massless case

(d) Discrete symmetries: C, P, T

5. Interaction (scalar case)

(a) Klein-Gordon real field. Propagator and causality

(b) Continuous symmetries Noether theorem: associated charges andcurrents. Energy-momentum tensor

(c) Cross Section and S matrix

(d) Interaction picture and S matrix

(e) Motivation for causal (free) fields

(f) Klein-Gordon complex field. Charge symmetry. Antiparticle.

(g) Wick theorem

(h) Tree level scattering for ^4 and ^3 theory

(i) Generalized Feynman rules

6. Scalar/Non-relativistic Quantum Electrodynamics (QED)

(a) Field for a massless spin-one particle: Electromagnetic field

(b) Quantization of scalar QED

(c) Quantization of Non-relativistic QED

(d) Elementary processes of scalar QED to O(e^2) (tree level Feynman diagrams).
For example: +K +K, ++ ++, + +,
K+K +, and the scalar Compton scattering .

(e) About gauge invariance. Ward identities

(f) Non-relativistic Quantum mechanics from Quantum Field Theory

(g) Interaction with a classical field

(h) Decays. Radiative transitions of hydrogen

Methodology

There will be teaching lectures where the theory will be explained in detail.

There will be teaching lectures where a selection of the list of exercises will be discussed.

The student should digest at home the theory explained in class, and perform the list of exercises suggested during the lectures.

Annotation: Within the schedule set by the centre or degree programme, 15 minutes of one class will be reserved for students to evaluate their lecturers and their courses or modules through questionnaires.

Activities

Title	Hours	ECTS	Learning Outcomes
Type: Directed			
Problems class	16	0.64	2, 1, 3, 4, 6, 7, 8, 13, 12, 15, 17, 16
Theoretical classes	33	1.32	2, 1, 3, 4, 5, 6, 7, 8, 13, 12, 15, 17, 18, 16
Type: Autonomous			
Discussion, work in groups	22	0.88	2, 1, 3, 4, 5, 6, 7, 8, 13, 19, 12, 15, 17, 18, 16
Problems solved in group or autonomously	30	1.2	2, 1, 3, 4, 5, 6, 7, 8, 13, 19, 12, 15, 17, 18, 16
Study of theoretical foundations	42	1.68	2, 1, 3, 4, 5, 6, 7, 8, 13, 19, 12, 15, 17, 18, 16

Assessment

1st partial exam: 45% of the grade.
2nd Partial exam: 50% of the grade.
Selective delivery of problems: 5% of the grade.

In order to be able to take part in the recovery exam, one should have been previously presented to both exams.
Examination of recovery of the two partials: 95% of the note. There is no minimum mark to be able to opt for the
recovery.

Unique assessment

Students who have accepted the single assessment modality will have to take a final test which will consist of a theory exam. You will then have to do a problem test. When it is finished, you will deliver the requested deliveries.The student's grade will be the weighted average of the three previous activities, where the theory exam will account for 45% of the grade, the problem exam 50% and the assignments 5%. If the final grade does not reach 5, the student has another opportunity to pass the subject through the remedial exam that will be held on the date set by the degree coordinator. In this test you will be able to recover 95% of the grade corresponding to theory and problems. The delivery part is not recoverable.

Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
Exam 1	45%	2	0.08	2, 1, 3, 4, 5, 6, 7, 8, 13, 14, 9, 12, 11, 15, 17, 16
Exam 2	50%	2	0.08	2, 1, 3, 4, 5, 6, 7, 8, 13, 14, 12, 11, 15, 17, 16
Homework	5%	1	0.04	2, 1, 3, 4, 5, 6, 7, 8, 13, 19, 10, 9, 12, 15, 17, 18, 16
resit exam	95%	2	0.08	2, 1, 3, 4, 5, 6, 7, 8, 13, 12, 15, 17, 16

Bibliography

• A. Cornellà and J.I. Latorre, Teoria clàssica de camps
• D. Lurie, Particles and Fields
• S. Weinberg, The Quantum Theory of Fields
• L.H. Ryder, Quantum Field Theory
• F.J. Yndurain, Elements of grup theory. https://arxiv.org/pdf/0710.0468
• C. Itzykson and J. Zuber, Quantum Field Theory
• S. Pokorsky, Gauge Field Theories
• B. Hatfield, Quantum Field Theory of Point Particles and Strings
• M. Peskin and D. Schroeder, An introduction to Quantum Field Theory
• J.F. Donoghue, E. Golowich, B.R. Holstein, Dynamics of the Standard Model

Software

General calculus programs like Mathematica