Universitat Autònoma de Barcelona

2021/2022

Introduction to Quantum Field Theory

Code: 42863
ECTS Credits: 6

Degree	Type	Year	Semester
4313861 High Energy Physics, Astrophysics and Cosmology	OT	0	1

The proposed teaching and assessment methodology that appear in the guide may be subject to changes as a result of the restrictions to face-to-face class attendance imposed by the health authorities.

Contact

Name: Antonio Miguel Pineda Ruiz

Email: AntonioMiguel.Pineda@uab.cat

Use of Languages

Principal working language: english (eng)

Prerequisites

It is recommended to have followed the course Introduction to the Physics of the Cosmos.

Objectives and Contextualisation

The main purpose of this course is to learn the basic concepts and techniques behind the theory of quantum fields, with aplications to elementary particle physics, in particular Quantum Electrodynamics.

Competences

- Apply the main principles to specific areas such as particle physics, astrophysics of stars, planets and galaxies, cosmology and physics beyond the Standard Model.
- Formulate and tackle problems, both open and more defined, identifying the most relevant principles and using approaches where necessary to reach a solution, which should be presented with an explanation of the suppositions and approaches.
- Use acquired knowledge as a basis for originality in the application of ideas, often in a research context.
- Use critical reasoning, analytical capacity and the correct technical language and formulate logical arguments.
- Use mathematics to describe the physical world, select the appropriate equations, construct adequate models, interpret mathematical results and make critical comparisons with experimentation and observation.

Learning Outcomes

1. Analyze the concept of renormalization and apply it in to electromagnetic processes.
2. Apply the language of Feynman diagrams in quantum field theory .
3. Apply quantum field theory electromagnetic processes.
4. Calculate cross sections of electromagnetic processes .
5. Understand the basics of quantum field theory.

Content

1. Introduction
(a) Fock space. Asymptotic states
(b) Natural units
(c) Cross Section and S matrix
(d) Interaction picture and S matrix
(e) Decays

2. Poincare Group. Reminder
(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 (*)

3. Interaction (scalar case)
(a) Klein-Gordon real field. Propagator and causality
(b) Motivation for causal (free) fields
(c) Wick theorem
(d) Continuous symmetries Noether theorem: associated charges and currents.
Energy-momentum tensor
(e) Klein-Gordon complex field. Charge symmetry. Antiparticle.

4. Quantum Electrodynamics (QED)
(a) SL(2,C) and non-unitary irreducible representations of the Lorentz group
(b) Dirac field: construction. Propagator, symmetries, spin: helicity and
quirality. Spin-statistics theorem

(c) Field for a massive spin-one particle: Proca field

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

(e) Quantization of QED
(f) S-matrix to O(e^2).
• Elementary processes of QED to tree level: Compton scattering,
$e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$, ...
• Feynman diagrams and computational techniques: traces, spin, ...

(g) Generalized Feynman rules
(h) About gauge invariance. Examples of Ward identity
(i) Soft Bremsstrahlung

5. Beyond tree level. Introduction
(a) Infinities and dimensional regularization.
(b) Vacuum polarization.
(c) Renormalization of the electric charge.
(d) Optical theorem.
(e) Dispersion relations
(f) Bound states in Quantum Field Theory: Hydrogen-like atoms (*)
(g) Renormalization of QED (*)

6. Beyond perturbation theory.
(a) LSZ formalism and crossing symmetry (examples)

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			
Theory and problems	45	1.8	1, 2, 3, 4, 5
Type: Autonomous			
Study, exercises	84	3.36	1, 2, 3, 4, 5

Assessment

Exam: 50%

Exercises delivery: 40%

Pariticipation in class and oral presentation of some exercises: 10%

Make-up exam: 50%. Necessary condition: To have 3.5 or more in the previous final mark.

Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
Exam	50%	3	0.12	1, 2, 3, 4, 5
Exercises delivery	40%	15	0.6	1, 2, 3, 4, 5
Oral presentations and active attendance in class	10%	3	0.12	1, 2, 3, 4, 5

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
• B. Hatfield, Quantum Field Theory of Point Particles and Strings
• S. Pokorsky, Gauge Field Theories
• 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