COURSE DATA

Data Subject	
Code	34272
Name	Quantum field theory
Cycle	Grade
ECTS Credits	6.0
Academic year	2023 - 2024

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
GONZALEZ ALONSO, MARTIN	185 - Theoretical Physics
PICH ZARDOYA, ANTONIO	185 - Theoretical Physics

SUMMARY

Quantum Field Theory unifies in a single conceptual framework the principles of quantum mechanics and special relativity. It is the appropriate formalism to describe microscopic physics (short distances, high energies) and, therefore, for the study of matter at its most basic level. This course provides an introduction to quantum field theory and its application to the physics of elementary particles, providing an overview of the standard theory of fundamental interactions (excluding gravity) and its phenomenological successes. The conceptual problems that appear when combining quantum physics and relativity, and the need for a formalism of many particles, are discussed. The basic formalism of field theory is developed, emphasizing the role of symmetries, and some simple applications in quantum electrodynamics, chromodynamics and the electroweak theory are presented. The aim is to familiarize students with the fundamental interactions among the constituents of matter and provide them the ability to calculate elementary processes at the lowest order in perturbation 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

The background needed for the development of the subject can be split into:

* Mathematical knowledge:
1. Vector spaces. Metric and scalar product.
2. Linear operators.
3. Fourier transform.
4. Dirac delta.
5. Mathematical analysis of a complex variable.

* Physical knowledge:
1. Lagrangian and Hamiltonian Mechanics.
2. Quantum Mechanics.
3. Special Relativity. Lorentz transformations.
4. Electric and magnetic fields: electromagnetic radiation.

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

SKILLS

- Knowledge and understanding of the conceptual problems that arise when combining quantum mechanics and special relativity.
- Know and understand the reasons for the existence of antimatter and its implications.
- Know and understand the origin of relativistic spin.
- Understand the principles governing the description of the microscopic world.
- Understand the role of symmetries in field theory and the canonical formalism of quantization.
- Know how to calculate probability amplitudes of simple processes from a Lagrangian.
- Ability to understand the fundamental interactions from symmetry, and predict their physical consequences.
- To know the most important aspects of quantum electrodynamics.

SOCIAL AND CROSS-CUTTING SKILLS

- Understand and be able to explain as simply as possible the laws governing the structure of matter and the universe in which we live.

The characteristic of the Degree in Physics:

- Develop critical thinking skills and application of scientific method.
- Be able to identify problems, including the similarities with others whose solution is known, and devise strategies for their solution.
- Develop the ability to plan and organize own learning, based on individual work, from the literature and other sources.
- Evaluate the different causes of a phenomenon and its relative importance.
- Identify the essential elements of a complex situation, make the approximations needed to construct simplified models that describe and to understand their behavior and in other situations.
- Be able to perform an update of existing information on a specific problem, sort and analyze it critically.
- Building capacity to work together in addressing the complex problems that require collaboration with others.
- Promote the acquisition of resources for speaking and writing to carry out a clear and coherent scientific argument.

DESCRIPTION OF CONTENTS

1. Particles and interactions

1.1 Elementary constituents of matter
1.2 Interactions and intermediate bosons
1.3 Special relativity
1.4 Lorentz transformations
1.5 Relativistic kinematics
1.6 Electromagnetic field

2. Relativistic quantum mechanics

2.1 Quantum mechanics
2.2 Correspondence principle
2.3 Klein-Gordon equation
2.4 Dirac equation
2.5 Solutions of the Dirac equation
2.6 Antiparticles
2.7 Need for a quantum field theory

3. Field theory quantization

3.1 Harmonic Oscillator
3.2 Classical field theory
3.3 Quantization
3.4 Symmetries and conservation laws

4. Particles without spin

4.1 Real Klein-Gordon field
4.2 Number representation for bosons
4.3 Complex Klein-Gordon field
4.4 Feynman propagator

5. Spin-1/2 particles

5.1 Number representation for fermions
5.2 Quantization
5.3 Fermionic propagator
5.4 Spin-statistics connexion

6. Interacting fields

6.1 S Matrix
6.2 Perturbation theory
6.3 Computation of amplitudes
6.4 Feynman rules

7. Observables

7.1 Cross sections and decay widths
7.2 Phase space
7.3 Dimensional analysis

8. Quantum electrodynamics

8.1 Gauge invariance
8.2 QED Lagrangian
8.3 Quantization of the electromagnetic field
8.4 Photon propagator
8.5 Feynman rules
8.6 Elementary processes at tree level

9. Quantum chromodynamics (complements)

9.1 Quark colour
9.2 Non-abelian gauge theories
9.3 QCD Lagrangian
9.4 Gluons
9.5 Asymptotic freedom
9.6 Confinement

10. Electroweak standard theory (complements)

10.1 Electroweak Lagrangian
10.2 W± and Z bosons
10.3 Massive vector field
10.4 The Higgs boson
10.5 Phenomenology

WORKLOAD

ACTIVITY	Hours	% To be attended
Theory classes	60,00	100
	0,00	100
Preparing lectures	45,00	0
Preparation of practical classes and problem	45,00	0
TOTAL	**150,00**	

TEACHING METHODOLOGY

During the academic year, four sessions per week will be performed, to be distributed on average in three lectures and one practical class:

• Lectures

The lectures will present the contents of the subject outlined above. They will emphasize the application of this theoretical knowledge to solve relevant physical questions and problems. The quantum field theory formalism will be applied to simple physical systems and the results will be compared with experimental data.

• Practical classes

Problems for each topic of the course will be solved weekly. A collection of problems for each chapter will be given in advance to the students.

EVALUATION

The assessment system is as follows:

1) Written examinations: One part will assess the understanding of the theoretical-conceptual aspects and the formalism of the subject, either with theoretical questions or through conceptual questions or simple cases. Another part will assess the applicability of the formalism, by solving problems, and the critical capacity regarding the obtained results. Proper argumentations, adequate justifications and clear and legible presentation will be important in both cases.

2) Continuous assessment: assessment of exercises and problems presented by students, questions proposed and discussed in class, oral presentation of problems solved or any other method that involves an interaction with students.

Continuous assessment will count in the final grade up to 30% as long as the exams grade is greater than or equal to 4 out of 10.

REFERENCES

Basic

- F. Mandl and G. Shaw, Quantum Field Theory (John Wiley & Sons, Chichester, 1993).
- M.E. Peskin and D.V. Schroeder, An Introduction to Quantum Field Theory (Addison-Wesley, Boulder, 1995).

Additional

- M. D. Schwartz, Quantum Field Theory and the Standard Model (Cambridge University Press, 2014).
- M. Srednicki, Quantum Field Theory (Cambridge University Press, 2007).
- D. Griffiths, Introduction to Elementary Particles (John Wiley & Sons, New York, 1987).
- J.D. Bjorken and S.D. Drell, Relativistic Quantum Mechanics (McGraw-Hill, New York, 1964).
- A. Pich, The Standard Model of Electroweak Interactions, arXiv:1201.0537 [hep-ph]; http://arxiv.org/pdf/1201.0537