COURSE DATA

DATA SUBJECT

Code: 34272
Name: Quantum field theory
Cycle: Undergraduate Studies
ECTS Credits: 6
Academic year: 2025-26

STUDY (S)

Degree	Center	Acad. year	Period
1105 - Degree in Physics	Facultat de Física	4	Second quarter

SUBJECT-MATTER

Degree	Subject-matter	Character
1105 - Degree in Physics	Complements of Physics	ELECTIVES

COORDINATION

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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 recommended 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.

COMPETENCES / LEARNING OUTCOMES

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Ability to collect and interpret relevant data in order to make judgements.

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.

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.

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.

Knowledge and understanding of the fundamentals of physics in theoretical and experimental aspects, and the mathematical background needed for its formulation.

Learning ability: be able to enter new fields through independent study, in physics and science and technology in general.

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.

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.

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 .

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 be able to communicate information, ideas, problems and solutions to both expert and lay audiences.

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 have developed the learning skills needed to undertake further study with a high degree of autonomy.

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.

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.

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 $W^\pm$ and Z bosons
10.3 Massive vector field
10.4 The Higgs boson
10.5 Phenomenology

WORKLOAD

PRESENCIAL ACTIVITIES

Activity	Hours
Theory	60,00
Total hours	**60,00**

NON PRESENCIAL ACTIVITIES

Activity	Hours
Attendance at other activities	0,00
Individual or group project	0,00
Independent study and work	0,00
Preparation of lessons	90,00
Preparation for assessment activities	0,00
Resolution of case studies	0,00
Total hours	**90,00**

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 grades for both parts (theoretical and problems) of the written exam are greater than or equal to 4 out of 10.

These evaluation criteria are common to the first and second calls.

REFERENCES

- 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).
- 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