COURSE DATA

DATA SUBJECT

Code: 43294
Name: Electroweak interactions
Cycle: Master's Degree
ECTS Credits: 6
Academic year: 2025-26

STUDY (S)

Degree	Center	Acad. year	Period
2150 - Master's degree in Advanced Physics	Facultat de Física	1	First quarter

SUBJECT-MATTER

Degree	Subject-matter	Character
2150 - Master's degree in Advanced Physics	Fundamental interactions	ELECTIVES

COORDINATION

NEBOT GOMEZ MIGUEL RUBEN

SUMMARY

In the Electroweak interactions course we will study the phenomenology of weak interactions starting with Fermi's contact theory. We will address its limitations and the introduction of vector boson mediators. The local gauge symmetry principle will be introduced together with its most relevant consequences and how it determines the interactions. We will analyse the spontaneous breaking of global symmetries and Goldstone's theorem. We will analyse spontaneous breaking of local symmetries and the generation of masses of vector boson mediators. We will study electroweak symmetry and the role of the Higgs scalar doublet in its breaking and the generation of fermion masses. We will address different phenomenological aspects of the electroweak theory: decays of W and Z gauge bosons, top quarks and the Higgs boson; production of W and Z gauge bosons and of the Higgs boson; the Cabibbo, Kobayashi and Maskawa mixing matrix, flavour physics and CP violation. We will also introduce aspects of neutrino physics: masses and oscillations.

PREVIOUS KNOWLEDGE

RELATIONSHIP TO OTHER SUBJECTS OF THE SAME DEGREE

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

OTHER REQUIREMENTS

COMPETENCES / LEARNING OUTCOMES

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Analizar una situación compleja extrayendo cuales son las cantidades físicas relevantes y ser capaz de reducirla a un modelo parametrizado.

Comprender de una forma sistemática el campo de estudio de la Física y el dominio de las habilidades y métodos de investigación relacionados con dicho campo.

Comprender la teoría electro-débil. Comprender como las interacciones pueden unificarse a partir de las cargas responsables.

Concebir, diseñar, poner en práctica y adoptar un proceso sustancial de investigación con seriedad académica.

Conocer y saber utilizar la invariancia de gauge local como punto de partida en la formulación de las interacciones fundamentales.

Elaborar una memoria clara y concisa de los resultados de su trabajo y de las conclusiones obtenidas en el área de la Física.

Estar en disposición para seguir los estudios de doctorado y la realización de un proyecto de tesis doctoral.

Evaluar la validez de un modelo o teoría propuesto por otros miembros de la comunidad científica.

Exponer y defender públicamente el desarrollo, resultados y conclusiones de su trabajo en el área de la Física.

Ostentar la preparación para tomar decisiones correctas en la elección de tareas y en su ordenación temporal en su labor investigadora y/o profesional.

Poseer la capacidad para el desarrollo de una aptitud crítica ante el aprendizaje que le lleve a plantearse nuevos problemas desde perspectivas no convencionales.

Realizar un análisis crítico, evaluación y síntesis de ideas nuevas y complejas en el área de la Física.

Saber construir modelos de acuerdo con el contenido en partículas y en simetrías de la teoría. Analizar y comprender los límites de validez de las teorías físicas.

Saber modelizar matemáticamente los problemas físicos sencillos nuevos, conectados con problemas conocidos. Ser capaz de expresar en términos matemáticos nuevas ideas.

Saber organizarse para planificar y desarrollar el trabajo dentro de un equipo con eficacia y eficiencia.

Ser capaz de gestionar información de distintas fuentes bibliográficas especializadas utilizando principalmente bases de datos y publicaciones internacionales en lengua inglesa.

Students should apply acquired knowledge to solve problems in unfamiliar contexts within their field of study, including multidisciplinary scenarios.

Students should be able to integrate knowledge and address the complexity of making informed judgments based on incomplete or limited information, including reflections on the social and ethical responsibilities associated with the application of their knowledge and judgments.

Students should communicate conclusions and underlying knowledge clearly and unambiguously to both specialized and non-specialized audiences.

Students should demonstrate self-directed learning skills for continued academic growth.

Students should possess and understand foundational knowledge that enables original thinking and research in the field.

DESCRIPTION OF CONTENTS

1. Phenomenology of weak interactions

The Fermi current-current contact interaction. V-A charged currents. C and P violation.
Leptonic, semi-leptonic and non-leptonic processes. Hadronic selection rules.

2. Steps towards electroweak unification

Shortcomings of the V-A contact theory. Unitarity. Vector boson mediation.
Neutral currents and unification of weak and electromagnetic interactions.

3. Gauge invariance

Quantum electrodynamics: U(1) gauge invariance. Covariant derivative and interactions.
Symmetries.
Non-abelian gauge invariance. Self-interactions.
SU(2) x U(1) gauge theory for chiral fermions.
Charged current couplings.
Electroweak mixing, neutral currents and couplings.

4. Symmetry breaking

Spontaneous breaking of global symmetries: Goldstone bosons.
Spontaneous breaking of local symmetries: gauge boson masses.
The scalar sector of the SU(2) x U(1) electroweak gauge theory.
Masses of W and Z gauge bosons. Unitary gauge.
The Higgs boson. Higgs-gauge boson couplings. Higgs self-couplings.

5. Completing the electroweak theory

Scalar-fermion (Yukawa) couplings.
Fermion mass eigenstates. Higgs-fermion couplings.
Charged and neutral currents.
Fermion mixings. The CKM matrix.
C, P and CP properties of fermion interactions.
Gauge fixing and Feynman rules.

6. Standard Model Phenomenology

Decays of Z and W gauge bosons. Decays of the top quark. Decays of the Higgs boson.
Production of Z and W gauge bosons.
Production of the Higgs boson.
Flavour and CP violation.
Neutral meson systems, the discovery of CP violation.
GIM mechanism.
More neutral mesons.

7. Neutrinos

Dirac, Weyl, Majorana fermions.
Neutrino masses.
Neutrino oscillations.

8. Advanced topics

Anomalies.
Physics beyond the Standard Model.

WORKLOAD

PRESENCIAL ACTIVITIES

Activity	Hours
Theory	40,00
Seminar	3,00
Other activities	3,00
Total hours	**46,00**

NON PRESENCIAL ACTIVITIES

Activity	Hours
Attendance at other activities	0,00
Individual or group project	21,00
Independent study and work	0,00
Preparation of lessons	43,00
Preparation for assessment activities	0,00
Resolution of case studies	40,00
Total hours	**104,00**

TEACHING METHODOLOGY

The contents of the course will be mainly addressed through participatory theoretical sessions (MD1), complemented by the discussion of papers (MD2) and sessions devoted to problems and problem solving (MD3 and MD4).

EVALUATION

The grading will have three components:
- Written exams concerning the theory and problem-solving sessions, with a 45% weight in the final grade (SE1).
- Continuous assessment of participatory attendance to the theory and problem sessions, with a 5% weight in the final grade (SE3).
- Assessment of homework through delivery of solved questions and problems, with a 50% weight in the final grade (SE5).

The pass the course the final grade must be equal or larger than 5/10.

This grading system applies to both the first and second call.

REFERENCES

Basic

- Schwartz M.D., Quantum Field Theory and the Standard Model (Cambridge UP 2014).

- Langacker P., The Standard Model and Beyond, 2nd edition (CRC 2017).

- Pich, A., The Standard Model of Electroweak Interactions, https://arxiv.org/abs/1201.0537 .

Complementary

- Aitchison I.J.R., Hey A.J.G., Gauge Theories in Particle Physics, A Practical Introduction, Vol. 1 From Relativistic Quantum Mechanics to QED, 4th edition (CRC 2013).
- Aitchison I.J.R., Hey A.J.G., Gauge Theories in Particle Physics, A Practical Introduction, Vol. 2 Non-Abelian Gauge Theories QCD and The Electroweak Theory, 4th edition (CRC 2013).

- Bailin D., Love A., Introduction to Gauge Field Theory (CRC 1993-2021).

- Burgess C.P., Moore G.D., The Standard Model, a Primer (Cambridge UP 2007).

- Cheng T.P., Li L.F., Gauge Theory of elementary particle physics (Oxford UP 1988).

- Cheng T.P., Li L.F., Gauge Theory of Elementary Particle Physics, Problems and Solutions (Oxford UP 2000).

- Goldberg D., The Standard Model in a Nutshell (Princeton UP 2017).

- Greiner W., Muller B., Gauge theory of weak interactions, 3rd edition (Springer 2000).

- Gross F., Relativistic Quantum Mechanics and Field Theory (Wiley VCH 2004).

- Iliopoulos J., Tomaras T.N., Elementary Particle Physics, The Standard Theory (Oxford UP 2021).

- Maiani L., Electroweak interactions (CRC 2016).

- Paschos E.A., Electroweak theory (Cambridge UP 2007).

- Peskin M.E., Schroeder D.V., An introduction to quantum field theory (Perseus 1995).

- Weinberg S., The Quantum Theory of Fields I, Foundations (Cambridge UP 1995).

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- Quevedo, F., Schachner A., Cambridge Lectures on The Standard Model, https://arxiv.org/abs/2409.09211 .

- Tong D., The Standard Model, https://www.damtp.cam.ac.uk/user/tong/sm/standardmodel.pdf .

- Romao J.C., Silva J.P., A resource for signs and Feynman diagrams of the Standard Model, Int.J.Mod. Phys.A 27 (2012) 1230025, https://arxiv.org/abs/1209.6213 .