Department of Physics

SI2390 Relativistic Quantum Physics
7.5 credits
Spring 2022, Period 3

General Information

"Relativistic Quantum Physics" is a course where important theories for elementary particle physics and symmetries are learned. During the course, it will be illustrated how relativistic symmetries and gauge symmetries can restrict "possible" theories. The course will give an introduction to perturbation theory and Feynman diagrams. The problem with divergencies will be mentioned and the concepts for regularization and renormalization will be illustrated.

The course is recommended to (and elective for) students in the first year of the Master's Programme in Engineering Physics (*i.e.*, the fourth year of the Degree Programme in Engineering Physics) at KTH specializing in physics in general and in theoretical physics in particular as well as to PhD students in physics and theoretical physics. The language of the course is English.

Intended Learning Outcomes

After completion of the course you should be able to:

- apply the Poincaré group as well as classify particle representations.
- analyze the Klein–Gordon and the Dirac equations.
- solve the Weyl equation.
- know Maxwell's equations and classical Yang–Mills theory.
- quantize Klein–Gordon, Dirac, and Majorana fields as well as formulate the Lagrangian for these fields.
- use perturbation theory in simple quantum field theories.
- formulate the Lagrangian for quantum electrodynamics as well as analyze this.

- derive Feynman rules from simple quantum field theories as well as interpret Feynman diagrams.
- analyze elementary processes in quantum electrodynamics.
- compute radiative corrections to elementary processes in quantum electrodynamics.

Syllabus

The course consists of two parts:

Part I. Relativistic quantum mechanics: Tensor notation. The Lorentz and Poincaré groups. Casimir operators. Irreducible representations of particles. The Klein–Gordon equation. The Dirac equation. The structure of Dirac particles. The Dirac equation: central potentials. The Weyl equation.

Part II. Introduction to relativistic quantum field theory: Neutral and charged Klein–Gordon fields. The Dirac field. The Majorana field. Maxwell's equations and quantization of the electromagnetic field. Introduction to Yang–Mills theory. Asymptotic fields: LSZ formulation. Perturbation theory. Introduction to quantum electrodynamics. Interacting fields and Feynman diagrams. Elementary processes of quantum electrodynamics. Introduction to regularization, renormalization, and radiative corrections.

Prerequisites

The following courses are mandatory:

- Quantum Physics
- Special Relativity Theory

The following course is recommended:

- Classical Theoretical Physics

Lectures and Lecturer

The course contains 36 h lectures (18×2 h), which will be given in English. The lecturer, course responsible, and examiner of the course is:

Professor Tommy Ohlsson
Department of Physics, KTH Royal Institute of Technology
Visiting address: Roslagstullsbacken 21, floor 5, room A5:1029
Telephone: 08-7908261
E-mail: tohlsson@kth.se

Course Literature

The course literature consists of one book (mainly):

- T. Ohlsson, *Relativistic Quantum Physics – From Advanced Quantum Mechanics to Introductory Quantum Field Theory*, Cambridge (2011)

Further recommended reading:

- A.Z. Capri, *Relativistic Quantum Mechanics and Introduction to Quantum Field Theory*, World Scientific (2002)
- W. Greiner, *Relativistic Quantum Mechanics – Wave Equations*, Springer (2000)
- F. Gross, *Relativistic Quantum Mechanics and Field Theory*, Wiley (1993)
- F. Mandl and G. Shaw, *Quantum Field Theory*, rev. ed., Wiley (1994)
- J. Mickelsson, T. Ohlsson, and H. Snellman, *Relativity Theory*, KTH (2005)
- M.E. Peskin and D.V. Schroeder, *Introduction to Quantum Field Theory*, Harper-Collins (1995)
- F. Schwabl, *Advanced Quantum Mechanics*, Springer (1999)
- S.S. Schweber, *An Introduction to Relativistic Quantum Field Theory*, Dover (2005)
- F.J. Ynduráin, *Relativistic Quantum Mechanics and Introduction to Field Theory*, Springer (1996)

Requirements

Hand in assignments (INL1; 4.5 ECTS credits) and an oral exam (TEN1; 3 ECTS credits).

Examination

The examination of the course will be a combination of homework problems (INL1) and an oral examination (TEN1).

INL1. There will be three sets of homework problems, which each consists of two parts, during the course. These will be distributed and should be handed in according to the following scheme:

Homework Problems	Out	In
Set # 1 – Part I	Lecture 5 (January 26, 2022)	February 2, 2022 @ 16:00–17:00
Set # 1 – Part II	Lecture 5 (January 26, 2022)	February 9, 2022 @ 18:00
Set # 2 – Part I	Lecture 11 (February 9, 2022)	February 16, 2022 @ 16:00–17:00
Set # 2 – Part II	Lecture 11 (February 9, 2022)	February 23, 2022 @ 16:00
Set # 3 – Part I	Lecture 17 (February 28, 2022)	March 7, 2022 @ 16:00–17:00
Set # 3 – Part II	Lecture 17 (February 28, 2022)	March 14, 2022 @ 16:00

TEN1. The oral examinations will take place after the last lecture of the course. Each examination will take approximately 15 minutes. The time for the examination will be agreed upon between the student and the examiner.

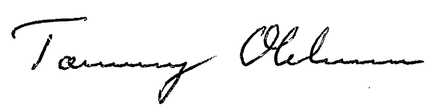
Grading

The different grades are: A, B, C, D, E, Fx, and F. The grades will be awarded according to the following scheme:

Grade	Homework Problems (INL1)	Oral Examination (TEN1)
F	< 50 % of all problems correct	Failed
Fx	< 50 % of all problems correct	Passed
Fx	≥ 50 % of all problems correct	Failed
E	≥ 50 % of all problems correct	Passed
D	≥ 60 % of all problems correct	Passed
C	≥ 70 % of all problems correct	Passed
B	≥ 80 % of all problems correct	Passed
A	≥ 90 % of all problems correct	Passed

In addition, you need to obtain at least 50 % on each homework problem set in order to obtain a passing grade (E or higher). If you obtain a total result of more than 50 %, but do not fulfill this criterion, you will be given the grade Fx and a chance to make a completing task for the grade E.

Good luck with the course!



Schedule and Program of Lectures

Schedule of Lectures

#	Week	Day	Date	Time	Room	Contents
1	3	Tuesday	January 18, 2022	10-12	FD41	Introduction
2		Wednesday	January 29, 2022	15-17	FD41	General description of relativistic states
3		Friday	January 21, 2022	10-12	FD41	The Klein–Gordon equation
4	4	Monday	January 24, 2022	10-12	FD41	The Dirac equation
5		Wednesday	January 26, 2022	10-12	FB51	—”—
S1		—”—	—”—	15-17	FD41	Seminar 1
6		Friday	January 28, 2022	10-12	FD41	The Dirac equation
7	5	Monday	January 31, 2022	10-12	FD41	Quantization of the non-relativistic string
8		Wednesday	February 2, 2022	10-12	FB55	Introduction to relativistic quantum field theory
9		Friday	February 4, 2022	10-12	FD41	Quantization of the Klein–Gordon field
10	6	Monday	February 7, 2022	10-12	FD41	Quantization of the Dirac field
11		Wednesday	February 9, 2022	10-12	FD41	Maxwell's equations and quantization of the electromagnetic field
S2		—”—	—”—	15-17	FD41	Seminar 2
12		Friday	February 11, 2022	10-12	FD41	Introduction to Yang–Mills theory
13	7	Wednesday	February 16, 2022	10-12	FD41	Asymptotic field and the LSZ formalism
14		Friday	February 18, 2022	10-12	FD41	Perturbation theory
15	8	Monday	February 21, 2022	10-12	FD41	—”—
16		Wednesday	February 23, 2022	10-12	FD41	—”—
S3		Friday	February 25, 2022	10-12	FD41	Seminar 3
17	9	Monday	February 28, 2022	10-12	FD41	Elementary processes of quantum electrodynamics
18		Friday	March 4, 2022	10-12	FB51	Introduction to regularization, renormalization, and radiative corrections

Program of Lectures

Below, RQP refers to the textbook T. Ohlsson, *Relativistic Quantum Physics – From Advanced Quantum Mechanics to Introductory Quantum Field Theory*, Cambridge (2011).

Lecture 0: Refresh chapter 1 in Mickelsson, Ohlsson & Snellman or some similar material on special relativity theory!

Lecture 1: Tensor notation. The Lorentz and Poincaré groups. Casimir operators. Irreducible representations of particles.
Literature: Chapter 1 in RQP.

Lecture 2: General description of relativistic one-particle states.
Literature: Chapter 1 in RQP.
For the interested student: E. Wigner, *On Unitary Representations of the Inhomogeneous Lorentz Group*, Ann. Math. **40**, 149 (1939).

Lecture 3: The Klein–Gordon equation. The Klein paradox.
Literature: Chapter 2 in RQP.

Lecture 4: The Dirac equation. Gamma "gymnastics".
Literature: Chapter 3 in RQP.

Lecture 5: The structure of Dirac particles. The Dirac equation: central potentials.
Literature: Chapter 3 in RQP.

Lecture 6: The hydrogenic atom. The Weyl equation.
Literature: Chapter 3 in RQP.

Lecture 7: Quantization of the non-relativistic string.
Literature: Chapter 4 in RQP.

Lecture 8: Introduction to relativistic quantum field theory.
Literature: Chapter 5 in RQP.

Lecture 9: Neutral and charged Klein–Gordon fields.
Literature: Chapter 6 in RQP.

Lecture 10: The Dirac field. The Majorana field.
Literature: Chapter 7 in RQP.

Lecture 11: Maxwell's equations and quantization of the electromagnetic field.
Literature: Chapter 8 in RQP.

Lecture 12: Introduction to Yang–Mills theory.
Literature: Chapter 9 in RQP.

Lecture 13: Asymptotic fields: LSZ (Lehmann–Symanzik–Zimmermann) formulation.
Literature: Chapter 10 in RQP.

Lecture 14: Perturbation theory.
Literature: Chapter 11 in RQP.

Lecture 15: see lecture 14.
Literature: Chapter 11 in RQP.

Lecture 16: Introduction to quantum electrodynamics. Interacting fields and Feynman diagrams.
Literature: Chapter 11 in RQP.

Lecture 17: Elementary processes of quantum electrodynamics.
Literature: Chapter 12 in RQP.

Lecture 18: Introduction to regularization, renormalization, and radiative corrections.
Literature: Chapter 13 in RQP.