Department of Physics

SI2390 Relativistic Quantum Physics
7.5 credits
Spring 2019, Period 3

You can find course information and some course material on the Internet:

`http://courses.theophys.kth.se/SI2390/`

General

"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 fourth year of the Degree Programme in Engineering Physics (*i.e.*, the first year of the Master's 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.

Aim

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, coordinator, and examiner of the course is:

Professor Tommy Ohlsson
Department of Physics, KTH
Visiting address: Roslagstullsbacken 21, rum A4:1039
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 cr) and an oral exam (TEN1; 3 cr).

Examination

The examination of the course will be a combination of homework problems and an oral examination. There will be three sets of homework problems during the course. These will be distributed and should be handed in according to the following scheme:

Homework problems	Out	In
Set # 1	Lecture 5 (January 22, 2019)	February 5, 2019
Set # 2	Lecture 11 (February 5, 2019)	February 19, 2019
Set # 3	Lecture 17 (February 26, 2019)	March 12, 2019

Note that collaboration with other students is allowed, but the hand-written solutions that you hand in should be written by you independently from the other students' solutions, *i.e.*, copying solutions is **not** allowed.

The oral examinations will take place after the last lecture of the course. Each examination will take approximately 20 minutes. The time for the examination will be agreed upon between the student and the examiner, but the student is obliged to take contact with the examiner.

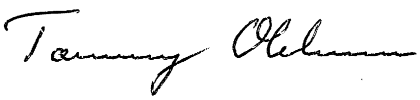
Grading

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	Oral examination
F	$<$ 40 % of all problems correct	Failed
Fx	$<$ 40 % of all problems correct	Passed
Fx	$\geq$ 40 % of all problems correct	Failed
E	$\geq$ 40 % of all problems correct	Passed
D	$\geq$ 60 % of all problems correct	Passed
C	$\geq$ 70 % of all problems correct	Passed
B	$\geq$ 80 % of all problems correct	Passed
A	$\geq$ 90 % of all problems correct	Passed

In addition, you need to obtain at least 40 % on each homework problem set in order to obtain a passing grade (E or higher). If you obtain a total result of more than 40 %, 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. For PhD students, the different grades are: P (pass) and F (fail).

Good luck with the course!



Schedule and Program of Lectures

Schedule of Lectures

#	Week	Day	Date	Time	Room	Contents
1	3	Tuesday	January 15, 2019	10-12	FB55	Introduction
2		Wednesday	January 16, 2019	15-17	FB55	General description of relativistic states
3		Friday	January 18, 2019	10-12	FB55	The Klein–Gordon equation
4	4	Monday	January 21, 2019	10-12	FB55	The Dirac equation
5		Tuesday	January 22, 2019	10-12	FD55	—"—
6		Friday	January 25, 2019	10-12	FD41	—"—
7	5	Monday	January 28, 2019	10-12	FB55	Quantization of the non-relativistic string
8		Tuesday	January 29, 2019	10-12	FB55	Introduction to relativistic quantum field theory
9		Friday	February 1, 2019	10-12	FD41	Quantization of the Klein–Gordon field
10	6	Monday	February 4, 2019	10-12	FB55	Quantization of the Dirac field
11		Tuesday	February 5, 2019	10-12	FB55	Maxwell's equations and quantization of the electromagnetic field
12		Friday	February 8, 2019	10-12	FB55	Introduction to Yang–Mills theory
13	7	Tuesday	February 12, 2019	10-12	FB55	Asymptotic field and the LSZ formalism
14		Friday	February 15, 2019	10-12	FB51	Perturbation theory
15	8	Tuesday	February 19, 2019	10-12	FB55	—"—
16		Friday	February 22, 2019	10-12	FB51	—"—
17	9	Tuesday	February 26, 2019	10-12	FB55	Elementary processes of quantum electrodynamics
18		Friday	March 1, 2019	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.
Lecture notes: 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.