Kursanalys - KTH[1]

Formulär för kursansvarig.
Kursanalysen utförs under kursens gång.
Nomenklatur: F – föreläsning, Ö – övning, R – räknestuga, L – laboration, S – seminarium)

KURSDATA Obligatorisk del [2]

Kursens namn	**Kursnummer**
Relativistisk kvantfysik	SI2390
Kurspoäng och poäng fördelat på exam-former	**När kursen genomfördes**
7,5 högskolepoäng (INL1, 4,5 högskolepoäng och TEN1, 3 högskolepoäng)	Läsåret 2018/2019 (period 3)
Kursansvarig och övriga lärare	**Undervisningstimmar, fördelat på F, Ö, R, L, S**
Professor Tommy Ohlsson	18 x 2h F

Antal registrerade studenter	24
Prestationsgrad efter 1:a examenstillfället, i %	85,8
Examinationsgrad efter 1:a examenstillfället, i %	70,8

MÅL

Ange övergripande målen för kursen

Efter fullgjord kurs skall du kunna:

- tillämpa Poincarégruppen samt klassificera partikelrepresentationer.
- analysera Klein–Gordon- och Diracekvationerna.
- lösa Weylekvationen.
- känna till Maxwells ekvationer och klassisk Yang–Mills-teori.
- kvantisera Klein–Gordon-, Dirac- och Majoranafält samt ställa upp Lagrangetätheter för dessa fält.
- använda störningsteori inom enkla kvantfältteorier.
- ställa upp Lagrangetätheten för kvantelektrodynamik samt analysera denna.
- härleda Feynmanregler utifrån enkla kvantfältteorier samt tolka Feynmandiagram.
- analysera elementära processer i kvantelektrodynamik.
- beräkna strålningskorrektioner för elementära processer i kvantelektrodynamik.

Ange hur kursen är utformad för att uppfylla målen

Kursen är utformad så att föreläsningar och egna självstudier skall leda till att studenterna kan lösa skriftliga inlämningsuppgifter samt svara på teorifrågor och därmed uppfylla målen för kursen.

Eventuellt deltagande i länkmöte före kursstart

Synpunkter från detta

-

[1] Instruktioner till kursanalysformulär sist i dokumentet
[2] Rektors beslut: http://www.kth.se/info/kth-handboken/II/12/1.html

Kursens pedagogiska utveckling I

Beskriv de förändringar som gjorts sedan förra kursomgången. (Berätta även för studenterna vid kursstart)

Inga förändringar har gjorts sedan föregående kursomgång.

Kontakt med studenterna under kursens gång

Studenter i årets kurs-nämnd:	**Namn**	**E-post** (lämnas blank vid webbpublicering)

Resultat av formativ mittkursenkät

Resultat av kursmöten

Kontakt med övriga lärare under kursens gång

Kommentarer

-

Kursenkät; teknologernas synpunkter Obligatorisk del [3]

Att komma ihåg:

1) Uppmana, mha kursnämnden, till ifyllande av kursenkät i anslutning till / just efter slutexaminationen
2) Delge kursnämnden enkäten
3) Publicera enkäten under en kortare tid

Period, då enkäten var aktiv	2019-03-13 – 2019-03-29
Frågor, som adderades till standardfrågorna	What is your overall impression of the course? How would you rate the difficulty of the course? Has there been much overlap with other courses? How were the homework problems? How was the oral examination? What is your opinion about the course description and the administration of the course? What is your opinion about the course literature? How were the lectures? Please, enter any further comments on the course below.
Svarsfrekvens	60 %
Förändringar sedan förra genomförandet	-
Helhetsintryck	Enligt kursenkäten svarade de flesta av studenterna att de var mycket eller ganska nöjda med kursen i sin helhet.
Relevanta webb-länkar	-

Kursansvarigs tolkning av enkät

Positiva synpunkter	Se bilaga.
Negativa synpunkter	Se bilaga.
Var kursen relevant i förhållande till kursmålen?	-
Syn på förkunskaperna	-
Syn på undervisningsformen	Föreläsningarna ansågs vara mycket bra eller bra av en majoritet av studenterna.
Syn på kurslitt/kursmaterial	Kurslitteraturen ansågs vara bra eller medelbra av en majortitet av studenterna.

[3] Rektors beslut: http://www.kth.se/info/kth-handboken/II/12/1.html

Syn på examinationen	Inlämningsuppgifterna ansågs vara svåra av en majoritet av studenterna, medan de muntliga tentamina ansågs vara lätta eller medelsvåra.
Speciellt intressanta kommentarer	Se bilaga.

Synpunkter från övriga lärare efter avslutad kurs

Vad fungerade bra	-
Vad fungerade mindre bra	-

Resultat av kursnämndsmöte efter examination

Studenternas sammanfattn.	-
Förslag till förändringar	-
Länk till kursnämndsprot.	-

Kursansvarigs sammanfattande berättelse

Helhetsintryck	Jag är i stort sett mycket nöjd med utfallet av kursen. Studenterna hade, som tidigare år, liknande förkunskaper. Antalet studenter var ungefär detsamma som föregående år.
Positiva synpunkter	Se bilaga med resultat av kursenkät.
Negativa synpunkter	Se bilaga med resultat av kursenkät.
Syn på förkunskaperna	-
Syn på undervisningsformen	-
Syn på kurslitt/kursmaterial	Läroboken, som har använts sju gånger tidigare, fungerar bra att använda som kurslitteratur i kursen, vilken är Tommy Ohlsson, Relativistic Quantum Physics (Cambridge University Press, 2011).
Syn på examinationen	Jag är på det stora hela nöjd med hur examinationen har fungerat och har inga planer på att förändra den tills nästa kursomgång.

Kursens pedagogiska utveckling II Obligatorisk del [4]

Hur förändringarna till denna kursomgång fungerade	-
Förändringar som bör göras inför nästa kursomgång	Jag tror att det kan vara bra att fundera på att byta föreläsare i kursen, eftersom nuvarande föreläsare har skrivit läroboken och har haft kursen 13 gånger. Jag tycker att det vore bättre att kursen skulle ges under två perioder istället för en period, eftersom det ger studenterna mer tid att "smälta" kursmaterialet som uppfattas som svårt i allmänhet av studenterna.

Övrigt

Kommentarer

Bilagor:

1. Kurs-PM: SI2390 Relativistic Quantum Physics, 7.5 ECTS credits

2. Obligatoriska inlämningsuppgifter [Homework Problems #1-#3 in SI2390 Relativistic Quantum Physics, 7.5 credits – Spring 2019, Periods 3]

3. Resultat av: Relativistic Quantum Physics, SI2390, vt 2019

[4] Rektors beslut: http://www.kth.se/info/kth-handboken/II/12/1.html

Instruktioner till kursanalysformulär

1) Kursanalysformuläret fylls i interaktivt; fälten expanderar automatiskt.
2) Fyll i fälten inom en månad efter kursens slut. (Viktigt krav från KTH!)
Skicka sedan till studierektor (som vidarebefordrar till prefekt och programansvarig).
3) Försök att ge så kompletta uppgifter som möjligt.
Tänk på att kursanalysen är ett hjälpmedel inte bara för teknologerna, utan även för Dig som lärare.
4) Med ”prestationsgrad” avses antalet presterade poäng hittills på kursen (inlämningsuppgifter, projektuppgifter, laborationer etc.) dividerat med antalet möjliga poäng för de registrerade studenterna. Med ”examinationsgrad” avses antalet studenter av de registrerade, som klarat samtliga kurskrav. Kurssekreteraren hjälper gärna till här.
5) Kontakten med studenterna:

- Etablera kursnämnd under kursens första vecka (minst två studerande, gärna genusbalanserad).
- Lämplig bonus till kursnämndsdeltagarna är fri kurslitteratur.
- Om kursnämnd ej kan etableras, skall sektionens studienämndsordförande (SNO) kontaktas genast (se www.ths.kth.se/utbildning/utbildningsradet.html för kontaktuppgifter).
- Kursnämnden skall sammanträda under kursens gång, exempelvis i halvtid. Har mittkursutvärdering genomförts, skall den diskuteras då.
- Kursnämnden skall även ha ett möte efter det att studenterna har besvarat kursutvärderingen och kursnämndens studenter fått tillgång till resultaten. Undantaget är kurser i period fyra, där mötet bör ske direkt efter examinatioinen är avslutad för att analysen skall vara klar innan sommaren.
- Under det avslutande kursnämndsmötet bör studenterna föra protokoll. Detta protokoll skall kursansvarig få senast en vecka efter mötet.
- Det är kursansvarigs ansvar att kalla till kursnämndsmöten.

Slutligen, tänk på:

- det är viktigt att kursanalysen tydligt *visar utvecklingen av kursens kvalitet* från ett läsår till nästa.
- möjligheten att lägga ut kursanalysen på kurshemsidan.
- spara kursanalysen till förberedelsearbetet inför nästa kursomgång.

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.

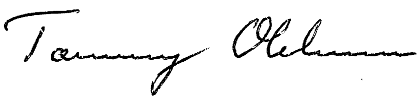
Grading

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.

Physics

Homework Problems #1 in SI2390 Relativistic Quantum Physics, 7.5 credits Spring 2019, Period 3

Deadline: February 5, 2019 @ 16:00

Examiner: Prof. Tommy Ohlsson
(Telephone: 08-790 8261; E-mail: `tohlsson@kth.se`)

Note! 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.

GOOD LUCK!

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1. Given an infinitesimal Lorentz transformation

$$\Lambda^{\mu}{}_{\nu} = \delta^{\mu}_{\nu} + \omega^{\mu}{}_{\nu},$$

show that the infinitesimal parameters $\omega_{\mu\nu}$ are antisymmetric.

2. a) Show that

$$\mathrm{tr}(\gamma^{\mu}\gamma^{\nu}\gamma^{5}) = 0.$$

b) Compute $\gamma_{\mu}\gamma^{5}\gamma^{\mu}\gamma^{5}$.

3. a) Determine the Hamiltonian $H = \beta m + \boldsymbol{\alpha}\cdot\mathbf{p}$ using the Dirac equation for a free particle $(\mathrm{i}\gamma^{\mu}\partial_{\mu} - m\mathbb{1}_4)\psi(x) = 0$.

b) Does this Hamiltonian commute with any of the three operators $\mathbf{L} = \mathbf{x}\times\mathbf{p}$ (angular momentum), $\mathbf{S} = \boldsymbol{\Sigma}/2$ (spin), where $\boldsymbol{\Sigma} = \mathrm{i}\boldsymbol{\gamma}\times\boldsymbol{\gamma}/2$, and $\mathbf{J} = \mathbf{L}+\mathbf{S}$ (total angular momentum)?

4. *Dirac equation for a constant potential.* Assume a Dirac electron of mass m in an attractive electrostatic potential

$$V(z) = \begin{cases} 0, & z<0,\ z>a \\ -V_0, & 0<z<a \end{cases},$$

where V_0 is a positive constant. Find the energy levels, *i.e.* compute the eigenvalue spectrum of the Dirac electron.

Physics

Homework Problems #2 in SI2390 Relativistic Quantum Physics, 7.5 credits Spring 2019, Period 3

Deadline: February 19, 2019 @ 16:00

Examiner: Prof. Tommy Ohlsson
(Telephone: 08-790 8261; E-mail: `tohlsson@kth.se`)

Note! 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.

GOOD LUCK!

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1. Consider the Lagrangian density

$$\mathcal{L} = \frac{1}{2}\left[\left(\frac{\partial\phi}{\partial t}\right)^2 - \left(\frac{\partial\phi}{\partial z}\right)^2 - m^2\phi^2\right],$$

where $\phi = \phi(t,z)$ is a generalized coordinate.

a) Find the conjugate momentum π to the field ϕ.

b) Suppose the field is expanded in normal modes

$$\phi(t,z) = \sum_{n=-\infty}^{\infty} c_n\left[a_n\phi_n(t,z) + a_n^\dagger\phi_n^*(t,z)\right],$$

where the operators a_n satisfy the commutation relations

$$[a_n, a_{n'}] = \left[a_n^\dagger, a_{n'}^\dagger\right] = 0, \quad \left[a_n, a_{n'}^\dagger\right] = \delta_{nn'}.$$

Find the coefficients c_n, which will ensure that the canonical commutation relations assume the standard form

$$[\phi(t,z), \pi(t,z')] = \mathrm{i}\delta(z-z').$$

2. Using the Klein–Gordon Feynman propagator

$$\Delta_F(x) = \frac{1}{(2\pi)^4} \int \mathrm{e}^{-\mathrm{i}k\cdot x} \frac{1}{k^2 - m^2 + \mathrm{i}\epsilon} \, \mathrm{d}^4k,$$

show that it satisfies the inhomogeneous Klein–Gordon equation

$$(\Box + m^2)\Delta_F(x) = -\delta(x).$$

3. If the charged field $\phi = (\phi_1 + \mathrm{i}\phi_2)/\sqrt{2}$, where ϕ_1 and ϕ_2 are commuting Hermitian fields, show that the Lagrangian density for the charged field ϕ,

$$\mathcal{L} = \partial_\mu \phi^\dagger \partial^\mu \phi - m^2 \phi^\dagger \phi,$$

can be written as the sum of two *independent* Lagrangian densities

$$\mathcal{L} = \mathcal{L}_1 + \mathcal{L}_2,$$

where each density $\mathcal{L}_i$ is multiplied by an overall factor of 1/2 compared with the Lagrangian density for its charged counterpart.

4. Find the equation of motion for the following Lagrangian

$$\mathcal{L} = -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} + \frac{1}{2} M^2 A_\mu A^\mu - j_\mu A^\mu.$$

Physics

Homework Problems #3 in SI2390 Relativistic Quantum Physics, 7.5 credits Spring 2019, Period 3

Deadline: March 12, 2019 @ 16:00

Examiner: Prof. Tommy Ohlsson
(Telephone: 08-790 8261; E-mail: `tohlsson@kth.se`)

Note! 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.

GOOD LUCK!

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1. For a free Dirac field ψ, compute the following correlation functions

$$\langle 0|T[\psi(x)\psi(y)\psi(z)]|0\rangle \quad \text{and} \quad \langle 0|T[\psi(x)\bar{\psi}(y)\bar{\psi}(z)\psi(w)]|0\rangle,$$

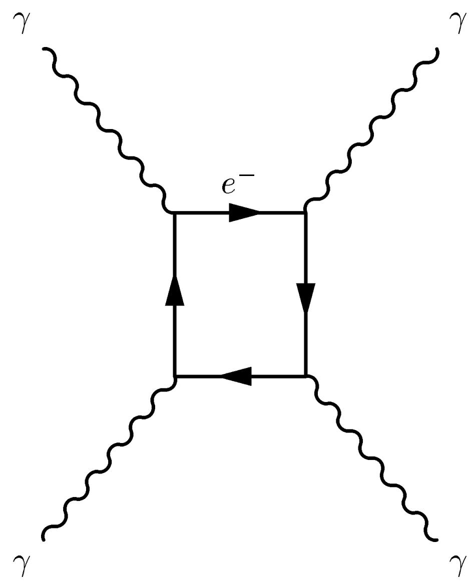
where $|0\rangle$ is the ground state (vacuum) of the free Dirac theory.

2. *Decay of a scalar particle.* Consider the following Lagrangian, involving two real scalar fields Φ and ϕ:

$$\mathcal{L} = \frac{1}{2}\partial_\mu\Phi\partial^\mu\Phi - \frac{1}{2}M^2\Phi^2 + \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2 - \mu\Phi\phi^2.$$

The last term is an interaction that allows a Φ particle to decay into two ϕ particles, provided that $M > 2m$. Assuming that this condition is fulfilled, calculate the lifetime of the Φ particle to lowest order in the coupling constant μ.

3. *Photon-photon scattering in QED.* a) Write down the amplitude for the Feynman electron box diagram shown in the following figure:



which contributes to photon-photon scattering. Let p_i and ϵ_i be the 4-momentum and polarization of photon i, respectively.
b) By counting powers of 4-momentum in the numerator and denominator, is the above diagram finite or infinite?

4. *Decay of a scalar particle.* Consider the following Lagrangian, involving two real scalar fields Φ and ϕ:

$$\mathcal{L} = \frac{1}{2}\partial_\mu \Phi \partial^\mu \Phi - \frac{1}{2}M^2\Phi^2 + \frac{1}{2}\partial_\mu \phi \partial^\mu \phi - \frac{1}{2}m^2\phi^2 - \mu\Phi\phi^2.$$

The last term is an interaction that allows a Φ particle to decay into two ϕ particles, provided that $M > 2m$. Using dimensional regularization, determine the one-loop self-energy of the Φ particle, *i.e.*, $-\mathrm{i}\Pi(p^2)$.

Resultat av: Relativistic Quantum Physics, SI2390, vt 2019

Status: Avslutad
Publicerad under: 2019-03-13 - 2019-03-29
Antal svar: 15
Procent av kursdeltagarna som svarat: 60%
Kontaktperson: Tommy Ohlsson

What is your overall impression of the course?

15 svarande

Very positive	5	33%
Quite postive	6	40%
Neutral - no opinion	3	20%
Quite negative	1	6%
Very negative	0	0%

- The topic is a very interesting one. However, I feel that it can be presented and examinated in better ways. I like that there is an oral exam which covers things that may be missed from only doing homework problems. There is however a problem with having homework problems as the examination which decides the grade. The homework problems were quite difficult, so you want to spend time with them and be confident that you have solved them correctly. And since the other problems available (in the book) are of similar difficulty you want to tackle the homework problems at the start. Naturally, you don't understand every concept immediately, so you want to discuss and ask questions to gain a better understanding of the topic as a whole. Understandably, the examiner doesn't want to answer every question in detail, as it could be of too much help with the homework problems, which in this course would be equivalent to having the examiner giving

too detailed answers during an exam. In other courses the homework problems often only give some bonus points, and giving detailed answers to questions relating to these are not as much of a problem. In courses like that, the homeworks are to help the students understand the topic, whereas in this course it felt that the homeworks were only a means of examination. To conclude, the way of examination used in this course made it more difficult to understand the topic, which is unfortunate as it is a very interesting one. Perhaps less time could be spent on the first part "Relativistic Quantum Mechanics", so that more time could be spent on the second part "Introduction to relativistic quantum field theory". It feels strange to spend so much time on something which we conclude doesn't work. Quantum field theory is not a trivial topic. The more time given to understand it, the better. (Quite postive)

- Det hade varit bra att ha en mer utförlig lista över frågeställningar eller vad som var centralt. Jag förstår att man ej kan ha en lista av frågor så att det slutar med att folk sitter och memorerar just svaren till dem för muntan, men de är svårt att ta till sig material om man ej blivit ställd rätt frågor, så man måste reflektera över det man lärt sig. (Quite postive)

- I found the subject and overall theme very interesting but at the same time pretty hard to get a good grasp on. (Neutral - no opinion)

- I was looking forward to having this course. I thought and think that the topics are really interesting. Nevertheless, the teacher didn't really achieve to make me understand it. I know how to quantize the fields, the problems with each relativistic quantum equation, I know how to calculate Feymann diagrams, I know how to solve the Home Assignments, even I got a very good grade. But I know that I didn't get the physical understanding of the different theories. For me most of the steps during the course weren't explained, even some steps were named as postulates/axioms although they were deductions at all! I had to spend so much time looking for information in books and trying to deduce why things were like that (To really understand concepts). It's something that didn't happen to me with other courses, even with other more Theoretical courses (so abstract mathematics). In my opinion, the professor explanations and the course book were the reason for that. (Quite negative)

How would you rate the difficulty of the course?

15 svarande

Very difficult	1	6%
Quite difficult	12	80%
Average	2	13%
Easy	0	0%
Very easy	0	0%

- Svårt ämne, helt enkelt. (Very difficult)
- Some concepts may not be easily assimilated, but through readings and exercises it becomes clear. (Quite difficult)
- Although the math was no problem to follow, the concepts were difficult and I would like to see more focus on how to think about the subjects from a physical perspective so as to build more of an intuition. I felt as though I had to do a lot of pure memorizing and it was often hard to connect things. (Quite difficult)
- The course was difficult because, as the concepts were explained so bad, it was so difficult to understand and solve the home assignments. After spending time reading other books and understanding the concepts, the problems could be solved with no so much complications (and sometimes calculus). The oral exam was easy. You didn't need to understand perfectly the physics behind the theories, but just remembering some key concepts that were in bold in the course book. (Quite difficult)
- It is difficult conceptually to understand some concepts. Regarding the evaluation, it seemed pretty easy for me to pass the course, but hard to have an A, since a couple of exercices in the homework sheets were really difficult. (Average)

Has there been much overlap with other courses?

15 svarande

Far too much overlap	0	0%
Some overlap, but it was useful to go over the topics again	10	66%
Mostly unnecessary overlap	1	6%
No overlap	4	26%

- Only some special relativity as far as I can recall, which was only good to repeat. (Some overlap, but it was useful to go over the topics again)
- No problem here, but try not to express disappointment when you need to repeat something from a previous course that maybe not everyone remembers like it was yesterday. It just creates bad atmosphere. (Some overlap, but it was useful to go over the topics again)
- I think the overlap was no so much, and the overlap that the course had was so useful. Maybe a bit more overlap would be necessary, because I think the teacher took some knowledge for granted and we didn't know about it. (Some overlap, but it was useful to go over the topics again)
- I felt that the relativity overlap was very little, but on the other hand it was not really needed either. (No overlap)

How were the homework problems?

15 svarande

Very difficult	1	6%
Difficult	10	66%
Average	4	26%
Easy	0	0%
Very easy	0	0%

- *They were tricky sometimes, but not unsolvable. Discussing with other people helped a lot in concretising the ideas and theories into mathematics! (Difficult)*
- *It was sometimes hard to tell if I was on the right track. Also sometimes I felt like I would have to assume things not stated in the problem formulation nor the book for things to work. (Difficult)*
- *As I said, they were difficult because the explanations during the course weren't enough to solve them. Furthermore, in my opinion, these explanation were not clear, so you had to spend so much time to understand about the physics behind the theory. Once you really got them, the problems were easy problems with some calculus. (Difficult)*
- *Some very hard and some very simple problems. (Difficult)*
- *Without any exercises classes it was sometimes difficult to know the level of justification expected. However, there were good to understand the mathematics and the physics of the course. (Average)*
- *Easy to pass, hard to score perfect (Average)*
- *Rättningen av uppgifterna kändes stundvis elak. Rätt skall vara rätt, men här var det ibland som att det letades efter anledningar att dra av halva eller hela poäng. (Average)*

How was the oral examination?

15 svarande

Very difficult	0	0%
Difficult	1	6%
Average	6	40%
Easy	7	46%
Very easy	1	6%

- *Not very hard, but not very easy either. I felt that I knew the subject well and think that it was a fair examination. It is not very common for courses to have oral exams, but I can really appreciate the value it adds, especially to the examiner given that there is no written exam. Keep it! (Average)*
- *If you participated in the lectures it was quite clear what was most important to understand. So given that one understood the content of*

the lectures the oral exam was of average difficulty, which felt fair. For students not participating in the lectures I can imagine it would be difficult to know how to study for the oral exam. (Average)
- Muntan var bra, men täckte ej sista kapitlet, vilket kanske var till min fördel. (Average)
- Seemed like a normal oral examination that one would expect. (Average)
- Rather superficial questions if one takes into account how deep the topics covered are (Easy)
- You didn't need to understand perfectly the physics behind the theories, but just remembering some key concepts that were in bold in the course book. (Easy)

What is your opinion about the course description and the administration of the course?

15 svarande

Very good	7	46%
Good	7	46%
Average	1	6%
Poor	0	0%
Very poor	0	0%

- Course PM very good, but no need to spend the entire first lecture going over it. Just cover the essentials. (Very good)
- It is very clear and concise. (Very good)
- Overall good, I particularly liked that we got the homework back so quickly. The course results were also put into Ladok very fast. The only improvement I can think of would be to put information about where the oral exam is held for which times online, I could see some people miss out on that information if they miss a lecture or two, and it's always good to have information that is meant to be public available online. (Good)

What is your opinion about the course literature?

15 svarande

Very good	2	13%
Good	3	20%
Average	7	46%
Poor	2	13%
Very poor	1	6%

- As the course follows the book closely, it was very suitable. Clear and

concise. (Very good)
- The textbook provides a good overall guide to all aspects covered in the course. However, sometimes a more detailed explanation is needed (either to better understand some things or to, for example, be able to solve some harder homework problems) (Average)
- I liked that it was quite concise, but I think it would benefit from more examples and (like I said earlier) explaining how to think about things from a physical perspective, to give the reader better intuition. For example, I found it hard to write down the equations from Feynman diagrams with the given examples. Also the latter parts of the first chapter were really hard as someone who has never taken group-theory, even with the appendix. (Average)
- The course book is hard to understand the first time it is read. Only after following other books simultaneously does it make sense. Some parts of T.Ohlsson are excellent, but some parts are very hard to follow. (Average)
- The book was quite difficult to learn from. Some parts of the book had a lot of math with not much physical intuition, which made it more difficult to understand. I found myself thinking many times "How does this follow from the above?" after the word "Thus" had been used. Therefore, I think that many conclusions that are made are not as obvious for the reader as they may perhaps be for the author. For the second part of the course I feel that perhaps the book by Peskin and Schroeder (which does not treat the first part of the course) gives a more detailed discussion with more of the physical intuition explanations lacking from the course book. This book could be more clearly pointed to as additional reading, as it is a very good book. Nevertheless, at times it may be too detailed. Also, to be fair, it is the only book in the list of additional reading which I have spent enough time with to have an opinion on. (Poor)
- First, the course book is mainly a set of lecture notes of the course with some additional information and some insufficient historical facts. The course book was, in my opinion, incredible bad for people who have their first touch with Relativistic Quantum Physics. It does not explain about the concepts. It does not tell us why this is our next step, why we should assumme this or what this physically means. The book only makes a bit of sense when you know the concepts, and you want to remember how something was derived or similar. I had to read through lot of different books and spend so much time trying to understand what the book wanted to say with some sentences. Some steps were explained as postulates, but when I really understood it I realize they could have been deduced! The only positive thing was that there were other recommended books in the course literature. (Poor)
- Förklaringarna av Feynman diagram var oerhört bristande, på den nivån att det var näst intill omöjligt att lära sig det man behövde bara genom att läsa boken. Delkapitlet om Yang-Mills hoppade rätt in i ekvationer utan att ge nåt riktigt kontext. (Very poor)

How were the lectures?

15 svarande

Very good	4	26%
Good	9	60%
Average	1	6%
Poor	1	6%
Very poor	0	0%

- I really like that we had more lectures (18) instead of the customary 10-15 that a 7.5 credit course has. The slow tempo gave me personally much and allowed for more discussions and digestion of the content. (Very good)
- While the lectures themselves were clear, I found that they sometimes lacked some motivation and a more in depth physical discussion of what as happening (Good)
- The lectures followed the book closely, but with the perhaps less central concepts not being discussed (not a problem according to me). There were also details mentioned in the lectures that were missing from the book. However, as with the book I would have preferred more physical intuition inbetween all of the mathematical derivations. (Good)
- Bra föreläsare. (Good)
- Maybe it would be good to focus a little more on understanding the very abstract concepts of the course during the lectures, instead of mostly long calculations which you can read on your own. (Good)
- Hard subject but the lectures themselves were fine, nothing big to comment on. (Good)
- The lecture basically consist on summarizing the course book (which was mainly a set of lecture notes). My opinion is the same as the book. It has no good explanation about the concepts. By the way, the lectures were better than the lecture notes, because they had sometimes additional explanations (although not so many),they summarized only the relevant contents and especially because you could ask the teacher, and he really tried to help you. (Poor)

Please, enter any further comments on the course below.

- Course in accordance to my expectation of it! In accordance also with Advanced Quantum Mechanics and Special Relativity that creates a whole branch is theoretical physics studies !
- Well done. Despite the relatively complicated content, I feel like that I walk away with new knowledge that I retained well thanks to the course structure.
- Över lag bra kurs. Poincaré delen kändes lite frånkopplad resten av kursen.
- I liked the course! :)
- I did not like the fact, that the homework was graded and the exam was only pass/fail. In my opinion the learning outcome is higher if the

homework would just be there for practicing and understanding the subject. This way one could discuss it more (also with the teacher) and more stuff becomes clear. A graded exam is also more representative than the homework since one can always find solutions online. But there is no way to "cheat" yourself through an oral exam. Also I think there were not enough homework sheets. The subject is very complex and difficult and 3 exercise sheets are not enough to fully understand all of it. If there would be, lets say, a homework sheet per week, the amount of practice and level of understanding would be way higher. Besides all that I really enjoyed the course and can recommend it :)

- I think the teacher should think about putting more efforts in make the students understand the concepts and explain everything although he may consider it is something easy to deduce. He should abandone or modify the course literature. If not, at least give really good explanation during the lectures and give the information that the book is not enough to understand the course (I don't recommend this option). Maybe, the quantity of contents are too much for the time we have, but this is something I'm not sure about it. I think the teacher really take the teaching so serious and try to improve a lot. I think he has good intentions, but I think he is on the wrong way, and that he could help the students a lot in comparison to what he does. I hope these comments (which are just opinions, and maybe some of them are wrong, but at least is my perspective) would help him to change in a good way.

- I would enjoy some more "physical" aspects on the course and conceptual understanding. If this is possible under the scope of the course and the time frame, it would be great!
