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 2019/2020 (period 3)
Kursansvarig och övriga lärare	**Undervisningstimmar, fördelat på F, Ö, R, L, S**
Professor Tommy Ohlsson	18 x 2h F

Antal registrerade studenter	15
Prestationsgrad efter 1:a examenstillfället, i %	89,9
Examinationsgrad efter 1:a examenstillfället, i %	80,0

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)

Canvas har implementerats fullständigt i kursen.

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	2020-03-11 – 2020-03-25
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	85 %
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 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 dock ca tio mindre jämfört med föregående år. Jag hoppas att detta var en fluktuation och att antalet studenter går upp igen tills nästa kursomgång.
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 åtta 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	Jag tycker att det har varit lätt att använda Canvas i kursen.
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 14 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 2020, Periods 3]
3. Resultat av: Relativistic Quantum Physics, SI2390, vt 2020

[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 2020, 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 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 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 24, 2020)	February 7, 2020
Set # 2	Lecture 11 (February 7, 2020)	February 21, 2020
Set # 3	Lecture 17 (February 25, 2020)	March 10, 2020

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 15 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.

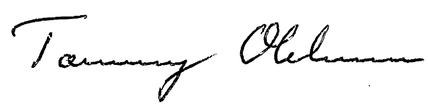
Grading

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.

Good luck with the course!



Schedule and Program of Lectures

Schedule of Lectures

#	Week	Day	Date	Time	Room	Contents
1	3	Wednesday	January 15, 2020	15-17	FB55	Introduction
2		Friday	January 17, 2020	10-12	FB55	General description of relativistic states
3		Monday	January 20, 2020	10-12	FB55	The Klein–Gordon equation
4	4	Tuesday	January 21, 2020	10-12	FB55	The Dirac equation
5		Friday	January 24, 2020	10-12	FB55	—”—
6		Monday	January 27, 2020	10-12	FB55	—”—
7	5	Tuesday	January 28, 2020	10-12	FB55	Quantization of the non-relativistic string
8		Friday	January 31, 2020	10-12	FB55	Introduction to relativistic quantum field theory
9		Monday	February 3, 2020	10-12	FB55	Quantization of the Klein–Gordon field
10	6	Tuesday	February 4, 2020	10-12	FB55	Quantization of the Dirac field
11		Friday	February 7, 2020	10-12	FB55	Maxwell's equations and quantization of the electromagnetic field
12		Monday	February 10, 2020	10-12	FB55	Introduction to Yang–Mills theory
13	7	Tuesday	February 11, 2020	10-12	FB55	Asymptotic field and the LSZ formalism
14		Friday	February 14, 2020	10-12	FB55	Perturbation theory
15	8	Tuesday	February 18, 2020	10-12	FB55	—”—
16		Friday	February 21, 2020	10-12	FB55	—”—
17	9	Tuesday	February 25, 2020	10-12	FB55	Elementary processes of quantum electrodynamics
18		Friday	February 28, 2020	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.

Physics

HOMEWORK PROBLEMS #1 IN SI2390 RELATIVISTIC QUANTUM PHYSICS, 7.5 CREDITS SPRING 2020, PERIOD 3

Deadline: February 7, 2020 @ 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 the transformation law of the 4-momentum P under Lorentz transformations

$$U^{-1}(\Lambda, 0)\, P^\mu\, U(\Lambda, 0) = (\Lambda^{-1})^\mu{}_\nu\, P^\nu,$$

show that $[M^{\rho\sigma}, P^\mu] = -\mathrm{i}(g^{\sigma\mu}P^\rho - g^{\rho\mu}P^\sigma)$.

Hint: Use the infinitesimal Lorentz transformation $\Lambda^\mu{}_\nu = \delta^\mu_\nu + \omega^\mu{}_\nu$, where $\omega^{\mu\nu} = -\omega^{\nu\mu}$, and the infinitesimal version of the unitary operator that represents the element $(\Lambda, 0)$ of the Poincaré group, i.e. $U(\Lambda, 0) = \exp(-\frac{\mathrm{i}}{2}\omega_{\mu\nu}M^{\mu\nu})$.

2. a) Show that

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

b) Compute $\gamma_\mu\gamma^\alpha\gamma^\beta\gamma^\mu$.

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. *The Klein paradox for the Dirac equation.* Solve the Dirac equation for a step-function potential on the form

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

where V_0 is a positive constant. Evaluate the current reflected and transmitted.

Physics

HOMEWORK PROBLEMS #2 IN
SI2390 RELATIVISTIC QUANTUM PHYSICS, 7.5 CREDITS
SPRING 2020, PERIOD 3

Deadline:	February 21, 2020 @ 16:00
Examiner:	Prof. Tommy Ohlsson
	(Telephone: 08-790 8261; E-mail: `tohlsson@kth.se`)
Note!	Collaboration with other students is allowed, but the handwritten 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. *Kaluza–Klein theory.* Assume a five-dimensional spacetime labeled by the coordinates (x, y), where $x = (x^\mu)$ are the usual coordinates of four-dimensional spacetime and y is a compact coordinate that parametrizes the extra dimension. Consider the Lagrangian density

$$\mathcal{L} = (\partial_N \phi^*)(\partial^N \phi) - m^2 \phi^* \phi,$$

where $N = 0, 1, 2, 3, 5$, $\phi = \phi(x, y)$ is complex scalar field compactified on a circle with radius R, and $m > 0$ is a mass. Since the fifth dimension is a circle, the field ϕ must be periodic in the coordinate y, i.e. $\phi(x, y) = \phi(x, y + 2\pi R)$.

a) Find the conjugate momentum $\pi(x, y)$ to the field $\phi(x, y)$.

b) Derive the free Klein–Gordon equation for the field ϕ in the five-dimensional spacetime.

Hint: Introduce

$$\Box_5 \equiv \Box - \frac{\partial^2}{\partial y^2},$$

where $\Box = \partial_0^2 - \nabla^2$ is the usual four-dimensional d'Alembertian operator.

c) Show that, from the point of view of a four-dimensional observer, this Klein–Gordon equation describes an infinite set of particles known as the Kaluza–Klein tower and compute their masses.

Hint: Use a Fourier series for the field $\phi(x, y)$ in the fifth coordinate y.

2. a) Suppose the field $\phi = \phi(t, z)$, where t is time and z describes a spatial direction, is a solution to the two-dimensional Klein-Gordon equation $(\Box_2 + m^2)\phi(t, z) = 0$, where $\Box_2 \equiv \partial_0^2 - \partial_z^2$, with periodic boundary conditions and expanded in normal modes as

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

where the operators a_n satisfy the commutation relations

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

the states $\phi_n(t, z) = \frac{1}{\sqrt{\ell}} \mathrm{e}^{i(k_n z - \omega_n t)}$ ($k_n = 2\pi n/\ell,\ n = 0, \pm 1, \pm 2, \ldots$ and $\omega_n > 0$), and

$$\int_0^\ell \phi_n^*(t, z) \phi_m(t, z)\, \mathrm{d}z = \delta_{nm}.$$

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

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

Are any other assumptions needed?

b) Find the equation of motion for the real scalar field $\phi = \phi(x)$, where $x = (x^\mu)$ is the 4-position vector, using the following Lagrangian

$$\mathcal{L} = \frac{1}{2} (\partial_\mu \phi) (\partial^\mu \phi) - \frac{1}{2} m^2 \phi^2 - \frac{1}{4} \lambda \phi^4.$$

In case the field $\phi(x)$ is reduced to a two-dimensional one $\phi(t, z)$, how will the equation of motion change and how does it compare to the one in Problem a)?

3. Using the Klein–Gordon Feynman propagator

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

show that it satisfies the inhomogeneous Klein–Gordon equation

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

4. By making the minimal coupling

$$\partial_\mu \phi(x) \to D_\mu \phi(x) = [\partial_\mu + \mathrm{i}eA_\mu(x)]\, \phi(x),$$
$$\partial_\mu \phi^\dagger(x) \to [D_\mu \phi(x)]^\dagger = [\partial_\mu - \mathrm{i}eA_\mu(x)]\, \phi^\dagger(x)$$

in the Lagrangian density of the complex Klein–Gordon field $\phi(x)$, derive the Lagrangian density $\mathcal{L}_I$ for the interaction of the charged bosons, described by the field $\phi(x)$, with the electromagnetic field $A_\mu(x)$.

Physics

Homework Problems #3 in
SI2390 Relativistic Quantum Physics, 7.5 credits
Spring 2020, Period 3

Deadline:	March 10, 2020 @ 16:00
Examiner:	Prof. Tommy Ohlsson
	(Telephone: 08-790 8261; E-mail: `tohlsson@kth.se`)
Note!	Collaboration with other students is allowed, but the handwritten 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. a) For a free Klein–Gordon field ϕ, compute the following correlation function

$$\langle 0|T[\phi(x_1)\phi(x_2)\phi(y)^4]|0\rangle,$$

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

b) For a free Dirac field ψ, compute the following correlation function

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

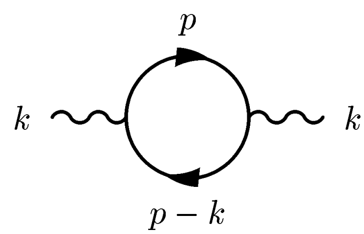
where $|0\rangle$ is the ground state (vacuum) of the free Dirac theory.

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 self-energy.* Write down the amplitude for the Feynman photon self-energy diagram shown in the following figure:



4. *Pseudoscalar Yukawa theory.* One part of the interaction Lagrangian for pseudoscalar Yukawa theory is given by

$$\mathcal{L}_{PY,\,\mathrm{int.}} = -\mathrm{i}g\bar{\psi}\gamma^5\psi\phi,$$

where ϕ is a neutral Klein–Gordon field, ψ is a Dirac field, and g is the coupling constant of the interaction. Using dimensional regularization, determine the one-loop vertex correction to this interaction. In addition, calculate the counterterm δg.

Teoretisk Fysiks kursutvärderingar

[Aktuella utvärderingar]
[Administrera]
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Alternativ:

[Lägg upp ny]
[Till min startsida]
[Logga ut]

Resultat av: Relativistic Quantum Physics, SI2390, vt 2020

Status: Avslutad
Publicerad under: 2020-03-11 - 2020-03-25
Antal svar: 12
Procent av kursdeltagarna som svarat: 85%
Kontaktperson: Tommy Ohlsson

What is your overall impression of the course?

12 svarande

Very positive	5	41%
Quite postive	7	58%
Neutral - no opinion	0	0%
Quite negative	0	0%
Very negative	0	0%

- *Well structured and organised course. (Very positive)*
- *The course content is really interesting! (Very positive)*
- *Good introductory course for getting feet wet in the subject. Quite challenging material, but not too much was expected from the student (which is good, otherwise it would be too hard). (Quite postive)*

How would you rate the difficulty of the course?

12 svarande

Very difficult	1	8%
Quite difficult	10	83%

Average	1	8%
Easy	0	0%
Very easy	0	0%

- Difficult concepts to grasp at times. (Quite difficult)
- Difficult in a good way. (Quite difficult)
- The last problemset was very difficult while the two first were more reasonable (Quite difficult)
- Difficult is good. (Quite difficult)
- It is a hard topic to grasp in my opinion. However the information was presented in bite sized chunks which made it easier to digest. (Quite difficult)
- The amount of material covered was quite large. So that might have affected the depth to which one could study certain parts of the material .I can't really think of a proper solution though as I didn't feel any of the material was unnecessary or redundant. So I'd just advice students taking the course to not slack off too much. An easy mistake to make is to study mainly the material required to solve the homeworks, which could then result in you doing poorly in the oral exam. Then again, you can take it again in a week or so, so it's not too bad. (Quite difficult)
- As mentioned previously, the material was hard (on occasion) but the student was seldom expected to understand everything regarding this. I think the course is probably rather 'easy' to pass, but 'quite difficult' to get a high grade in: on average it was average. (Average)

Has there been much overlap with other courses?

12 svarande

Far too much overlap	0	0%
Some overlap, but it was useful to go over the topics again	4	33%
Mostly unnecessary overlap	0	0%
No overlap	8	66%

- Special Relativity, TET (Some overlap, but it was useful to go over the topics again)
- I had taken Condensed Matter Theory earlier so a couple ideas were familiar from there. Otherwise, the only overlap would be in the special relativity part, but I think it is good to cover it couple times in different courses. (Some overlap, but it was useful to go over the topics again)
- Atleast very little that I can think of. (No overlap)
- I would say there was very little overlap. Though I never read the course in classical field theory which was almost a prerequisite. (No overlap)

How were the homework problems?

12 svarande

Very difficult	0	0%
Difficult	9	75%
Average	3	25%
Easy	0	0%
Very easy	0	0%

- The homework problems were difficult at times, but also do-able with the course material and the lectures. (Difficult)
- Hw3 was too difficult since almost everything we had to do was much more difficult than what was in the book (not problem 3) and sometimes not even covered in the book like the majority of problem 4. (Difficult)
- Difficult on average. I'd say that there was a rather large difference in dificulty within each set. E.g Question 1 and 3 were quite easy in Homework set #3 but question 4 was a lot harder than the others. (Difficult)
- The problems were good, but I felt a couple topics got missed out such as EM theory, Yang Mills, and LSZ formalism. (Difficult)
- I feel that handing in the problems digtally would have been much better than physical, handwritten copies. (Difficult)
- I think that they very at the appropriate level. (Average)
- I think they were a good mix of easier problems and more difficult problems, such that the lower grades were (quite easily) obtainable whereas the higher grades were much more demanding. (Average)

How was the oral examination?

12 svarande

Very difficult	0	0%
Difficult	0	0%
Average	8	66%
Easy	4	33%
Very easy	0	0%

- I think it was a good difficulty, though all the questions were quite specific. One student might get unlucky and fail because the questions were precisely the things they didn't study, or one student might get lucky and pass because they studied just the right things. I think it would not be unwise to mix in one or two broader, more general questions, to eliminate some of this randomness. (Average)
- Not too difficult, but maybe that's because I was well prepared and

had spent a lot of time on going through course notes. (Average)
- It was easy which I think it should be since it is a pass fail examination. (Easy)

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

12 svarande

Very good	6	50%
Good	5	41%
Average	1	8%
Poor	0	0%
Very poor	0	0%

- One knows what to expect of the course from Day 1. (Very good)

What is your opinion about the course literature?

12 svarande

Very good	1	8%
Good	4	33%
Average	6	50%
Poor	1	8%
Very poor	0	0%

- Good literature, however I find that sometimes it is a little bit lacking when explaining things, and formulae are just thrown my way. (Good)
- Sometimes it was difficult to follow, but in those situations it where possible to look up other sources to clear up most things. (Average)
- I think that it should clearly stated from the beginning of the lectures that the course book is not enough in itself to understand clearly and deeply how the Feynman diagrams are related to the scattering matrix. In general it is a good book that sums up all we need to know about the beginning of quantum field theory but it is not so great if we really want to understand all the subtle links between different concepts. (Average)
- Good in the sense that it matched, one to one, the course material (obviously, since it was written by the professor). The book was sometimes hard to get through, like it did not appreciate that this subject was entirely new for the reader. (Average)
- The course book is very well written and clear, but for a student learning the material for the first time it is quite dense. Example problems and solutions would help to get a better understanding of the topic. (Average)

- It almost never explains what we are actually doing. A lot of the things we did had much more depth to them when I started to look them up in other litterature like Peskin. This made the course harder to take in I feel like. (Average)
- It is quite good in many aspects but a bit lacking in others. Specifically, a proper derivation/motivation of various Feynman rules was kind of missing, so it would be good if you could provide handwritten notes/links to other material for that part. Overall, I would recommend other students taking this course to primarily follow the derivations etc from the course textbook, for which it is quite good, but also to maybe glance at a couple other textbooks for theorems/concepts etc and for anything that isn't clear. And wikipedia is your best friend for maths used in Physics. :) Of course, full disclaimer that this is all my personal opinion. (Average)

How were the lectures?

12 svarande

Very good	3	25%
Good	6	50%
Average	3	25%
Poor	0	0%
Very poor	0	0%

- The lectures made me understand things that I'm sure I would not have understood if I only read the course book (or any other book on the topic) (Very good)
- The lectures were very good. The course follows the book quite closely. So even if you miss some lectures, you can do okay. I wouldn't recommend missing though. (Very good)
- I wished there were a bit more emphasis on connecting the different parts of the course. Most of my study time I put into connecting different parts together to get how everything was related. Would also liked a bit more application, but I guess that comes more in the theoretical particle physics course so it is not as important. (Good)
- Would have been nice with some lectures with 15 min break. (Good)
- I did not attend lectures. (Average)

Please, enter any further comments on the course below.

- I think it did a good job in being an introductory course: providing some exposure to subjects that will recur and not demanding too much intermediate or advanced understanding.
- I think you should explain some mathematical steps a bit more since in the bachelor we no longer have complex analysis which means that residue calculus is completely new for a lot of the students.

- *It's quite a good follow up course to Advanced Quantum Mechanics and Special Relativity.*

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