Kursanalys - KTH

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

KURSDATA Obligatorisk del

Kursens namn	**Kursnummer**
Relativistisk kvantfysik	SI2390
Kurspoäng och poäng fördelat på exam-former	**När kursen genomfördes**
7,5 hp (INL1, 4,5 hp och TEN1, 3 hp)	Läsåret 2020/2021 (period 3)
Kursansvarig och övriga lärare	**Undervisningstimmar, fördelat på F, Ö, R, L, S**
Professor Tommy Ohlsson	18 x 2h F

Antal registrerade studenter	30
Prestationsgrad efter 1:a examenstillfället, i %	90,5
Examinationsgrad efter 1:a examenstillfället, i %	76,7

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 ska 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

-

Kursens pedagogiska utveckling I

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

Canvas har implementerats fullständigt i kursen. Quizzes i Canvas har införts som hälften av examinationen i kursmomentet INL1. Samtliga föreläsningar har spelats in och finns på KTH Play.

Kontakt med studenterna under kursens gång

Studenter i årets kurs-nämnd:	Namn	E-post (lämnas blank vid webbpublicering)
	Yashar Honarmandi	mas.ttfym@f.kth.se

Resultat av formativ mittkursenkät

Resultat av kursmöten

Kontakt med övriga lärare under kursens gång

Kommentarer

-

Kursenkät; teknologernas synpunkter Obligatorisk del

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 2021-03-17 – 2021-04-07

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 quizzes?
- How were the (hand-in) 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 did the lecture format (live on blackboard + recorded) work?
- How were the lectures?
- Would it be useful to have separate discussion sessions in the course?
- Please enter any further (non-covid-19-situation-related) comments on the course below.
- Please enter any further (covid-19-situation-related) comments on the course below.

Svarsfrekvens	66 %
Förändringar sedan förra genomförandet	Quizzes i Canvas har införts som hälften av examinationen i kursmomentet INL1, främst p.g.a. att hantera att antalet studenter i årets kursomgång var mer än dubbelt så många jämfört med föregående år. P.g.a. covid-19-situationen, så har kursen genomförts via Zoom, som har fungerat förvånansvärt bra. Samtliga föreläsningar ägde rum på Zoom och har spelats in. Föreläsningarna finns tillgängliga på KTH Play.
Helhetsintryck	Enligt kursenkäten svarade majoriteten av studenterna att de var mycket eller ganska nöjda med kursen i sin helhet. Det är min uppfattning att kursen kan bedrivas på distans även i framtiden, men naturligtvis också via vanlig konventionell undervisning. Det enda som jag tycker har saknats är den personliga kontakten med studenterna i klassrumsmiljö.
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. Från studenternas sida så har det framkommit att det vore önskvärt med seminarier/övningar/diskussionstillfällen som ett komplement till föreläsningarna. Tre tillfällen med seminarier/övningar/diskussionstillfällen kommer att införas i kursen tills nästa kursomgång.
Syn på kurslitt/ kursmaterial	Kurslitteraturen ansågs vara bra eller medelbra av en majortitet av studenterna.
Syn på examinationen	Inlämningsuppgifterna ansågs vara svåra av en majoritet av studenterna, medan de muntliga tentamina och de s.k. quizzes 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 mer än dubbelt så många jämfört med 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 nio 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 större planer på att förändra den tills nästa kursomgång.

Kursens pedagogiska utveckling II Obligatorisk del

Hur förändringarna till denna kursomgång fungerade	Jag tycker att det har varit lätt att använda Canvas i kursen. Quizzes i Canvas fungerade bra och kommer förslagsvis att användas under nästa kursomgång också. Att hålla föreläsningarna på Zoom fungerade förvånansvärt bra och kan komma att tillämpas igen i framtiden.
Förändringar som bör göras inför nästa kursomgång	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 2021, Periods 3]
3. Resultat av: Relativistic Quantum Physics, SI2390, vt 2021

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 2021, 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 27, 2021)	February 3, 2021 @ 16:00–17:00
Set # 1 – Part II	Lecture 5 (January 27, 2021)	February 10, 2021 @ 16:00
Set # 2 – Part I	Lecture 11 (February 10, 2021)	February 17, 2021 @ 16:00–17:00
Set # 2 – Part II	Lecture 11 (February 10, 2021)	February 24, 2021 @ 16:00
Set # 3 – Part I	Lecture 17 (March 3, 2021)	March 10, 2021 @ 16:00–17:00
Set # 3 – Part II	Lecture 17 (March 3, 2021)	March 17, 2021 @ 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	$\geq$ 50 % of all problems correct	Failed
E	$\geq$ 50 % 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 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	Monday	January 18, 2021	10-12	FD41	Introduction
2		Wednesday	January 20, 2021	10-12	FD41	General description of relativistic states
3		Friday	January 22, 2021	10-12	FB55	The Klein–Gordon equation
4	4	Monday	January 25, 2021	10-12	FD41	The Dirac equation
5		Wednesday	January 27, 2021	10-12	FD41	—”—
6		Friday	January 29, 2021	10-12	FD41	—”—
7	5	Monday	February 1, 2021	10-12	FD41	Quantization of the non-relativistic string
8		Wednesday	February 3, 2021	10-12	FD41	Introduction to relativistic quantum field theory
9		Friday	February 5, 2021	10-12	FD41	Quantization of the Klein–Gordon field
10	6	Monday	February 8, 2021	10-12	FD41	Quantization of the Dirac field
11		Wednesday	February 10, 2021	10-12	FD41	Maxwell’s equations and quantization of the electromagnetic field
12		Friday	February 12, 2021	10-12	FD41	Introduction to Yang–Mills theory
13	7	Wednesday	February 17, 2021	10-12	FD41	Asymptotic field and the LSZ formalism
14		Friday	February 19, 2021	10-12	FD41	Perturbation theory
15	8	Wednesday	February 24, 2021	10-12	FD41	—”—
16		Friday	February 26, 2021	10-12	FD41	—”—
17	9	Wednesday	March 3, 2021	10-12	FD41	Elementary processes of quantum electrodynamics
18		Friday	March 5, 2021	10-12	FA31	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 2021, Period 3

Deadlines:	Part I: Quiz on February 3, 2021 @ 16:00–17:00
	Part II: February 10, 2021 @ 16:00
Examiner:	Prof. Tommy Ohlsson
	(Telephone: 08-790 8261; E-mail: `tohlsson@kth.se`)
GOOD LUCK!	

Part I

1. a) Compute $\mathrm{tr}(\gamma^\mu \gamma^\nu)$, $\mathrm{tr}(\gamma^\mu \gamma^\nu \gamma^\rho)$, $\mathrm{tr}(\gamma^\mu \gamma^5)$, and $\mathrm{tr}(\gamma^\mu \gamma^\nu \gamma^5)$.

   b) Compute $\gamma^\mu \gamma^\nu \gamma_\mu$, $\not{p}\gamma^\mu \not{p}$, $\gamma^\mu \gamma^5 \gamma_\mu \gamma_5$, and $\gamma^\mu \gamma^\alpha \gamma^\beta \gamma_\mu$.

2. 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)?

Part II

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. *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 2021, Period 3

Deadlines:	Part I: Quiz on February 17, 2021 @ 16:00–17:00
	Part II: February 24, 2021 @ 16:00
Examiner:	Prof. Tommy Ohlsson
	(Telephone: 08-790 8261; E-mail: `tohlsson@kth.se`)
GOOD LUCK!	

Part I

1. 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

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

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)?

2. 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

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

What is the form of each density $\mathcal{L}_i$?

Part II

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. 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

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

Physics

HOMEWORK PROBLEMS #3 IN
SI2390 RELATIVISTIC QUANTUM PHYSICS, 7.5 CREDITS
SPRING 2021, PERIOD 3

Deadline: Part I: Quiz on March 10, 2021 @ 16:00–17:00
Part II: March 17, 2021 @ 16:00

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

GOOD LUCK!

Part I

1. a) For a free Klein–Gordon field ϕ, compute the following correlation functions

$$\langle 0|T[\phi(x)\phi(y)\phi(z)]|0\rangle \quad \text{and} \quad \langle 0|T[\phi(x)\phi(y)\phi(z)^4]|0\rangle,$$

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

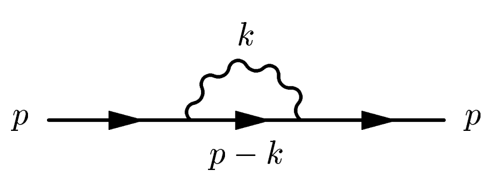
Note that the correlation function $\langle 0|T[\phi(x)\phi(y)\phi(z)^4]|0\rangle$ would only appear within an interacting theory, but this correlation function can still be computed.

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

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

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

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



Part II

1. *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.

2. Using dimensional regularization, determine the one-loop self-energy of the Φ particle, i.e. $-\mathrm{i}\Pi(p^2)$, in Problem II.1.

Teoretisk Fysiks kursutvärderingar

Aktuella utvärderingar
Administrera
Hjälpsida

Alternativ:
Lägg upp ny
Till min startsida
Logga ut

Resultat av: Relativistic Quantum Physics, SI2390, vt 2021

Status: Avslutad
Publicerad under: 2021-03-17 - 2021-04-07
Antal svar: 20
Procent av kursdeltagarna som svarat: 66%
Kontaktperson: Tommy Ohlsson

What is your overall impression of the course?

20 svarande

Very positive	5	25%
Quite postive	8	40%
Neutral - no opinion	2	10%
Quite negative	5	25%
Very negative	0	0%

- *I'm really satisfied with the learning outcome. I internalized them pretty well and this is surely related to the quality of the course (excluding my studies)* (Very positive)
- *Challenging but rewarding, is my general thought.* (Very positive)
- *I thought this course was difficult and I felt that much of it came from not understanding something and not being able to make sense of it from the book or by the lectures.* (Quite negative)
- *The course topics were very interesting and the preparation of the professor excellent. My negative impressions mainly come from some logistical problems on how the course is structured.* (Quite negative)

How would you rate the difficulty of the course?

20 svarande

Very difficult	6		30%
Quite difficult	10		50%
Average	4		20%
Easy	0		0%
Very easy	0		0%

- *This course took a long deal of time from me, due to the extreme conceptual difficulty of the topics, condensed in very few time.* *(Very difficult)*
- *It's difficult due to the size of the course and it requires a lot of searching outside of the course material to understand it.* *(Very difficult)*
- *I have struggled, but in the end overcome the problems.* *(Very difficult)*
- *It was very difficult but so is the topic it is trying to teach.* *(Very difficult)*
- *I felt as though it could have been made easier by introducing more mathematical rigour. As it was now, you often had to guess what exactly things meant mathematically. For me at least, it made the subject less transparent, since there was always some ambiguity in this regard.* *(Quite difficult)*
- *The course material is difficult, and the course was given quite quickly, making it difficult to really internalize the harder parts (such as the quantization of the EM-field and renormalization).* *(Quite difficult)*

Has there been much overlap with other courses?

20 svarande

Far too much overlap	0		0%
Some overlap, but it was useful to go over the topics again	11		55%
Mostly unnecessary overlap	1		5%
No overlap	8		40%

- *Some overlap with the course on analytical mechanics and classical field theory, especially regarding the electromagnetic lagrangian and classical Yang-Mills theory.* *(Some overlap, but it was useful to go over the topics again)*
- *Basically none* *(Some overlap, but it was useful to go over the topics again)*
- *The group theory and field theory limit were recognizable from the Analytical mechanics & classical field theory course.* *(Some overlap, but it was useful to go over the topics again)*
- *I have never had courses in Relativity Theory, hence, each topic was new for me.* *(No overlap)*
- *This course has nothing to do with my track. I took it for personal*

curiosity and knowledge. *(No overlap)*
- *I actually liked that there was little to none overlap, since I had taken all prerequisite courses. However, I do feel as though I would have benefited heavily from having taken analytical mechanics and classical field theory, which I hadn't done, since it is given in P4 each year, and the previous year we (who where supposed to start TTFYM in the autumn) where recommended to take solid state physics instead. I am in the theoretical physics track — so I cannot speak for the other tracks — however I cannot understand why solid state physics is recommended in favour of analytical mechanics and classical field theory, at least for our track. I have felt this way in most other courses as well, and I am yet actually use any knowledge from solid state physics in any other course. Therefore, since you choose the track in TTFYM directly anyway, why not actually recommend appropriate courses already in the third year when you have to choose courses to prepare for your master's programme? If solid state physics is important for some upcoming courses in the last year, why not recommend that we them in P4 during the first year of the master's programme instead?* *(No overlap)*

How were the quizzes?

20 svarande

Very difficult	0	0%
Difficult	5	25%
Average	11	55%
Easy	3	15%
Very easy	1	5%

- *Quizzes were never obvious and were based on exercises that were often difficult.* *(Difficult)*
- *They were somewhat difficult but most of my mistakes were made because I missed some detail when reading the question or the alternatives. (Yes, I know we were warned of this yet somehow it still happend.)* *(Difficult)*
- *Quite easy in the beginning but more challenging in the end of the course.* *(Average)*
- *The questions were simple, but one really had to understand why some options were wrong in order to exclude them, which was a bit tricky sometimes.* *(Average)*
- *Too easy, in fact. At least compared to the handed in homework.* *(Very easy)*

How were the (hand-in) homework problems?

20 svarande

Very difficult	4		20%
Difficult	14		70%
Average	2		10%
Easy	0		0%
Very easy	0		0%

- In the majority of the exercises, we need to use what we learned during the lectures but in a specific case never treated during the course. This was the main difficulty for me. A lot of assumptions were needed without knowing if they were good or not. (Very difficult)
- Hand in problems caused me a lot of stress, a long deal of time and few time to check everything. Distraction or minor errors have greatly penalised me on the final grade. (Very difficult)
- Challenging but rewarding. (Very difficult)
- Challenging! (Difficult)
- I think they SHOULD be difficult. (Difficult)
- Ranging from very easy to very hard. (Average)
- The hand-ins were mostly straightforward applications of the theory (Average)

How was the oral examination?

20 svarande

Very difficult	0		0%
Difficult	3		15%
Average	12		60%
Easy	5		25%
Very easy	0		0%

- The examination was very honest and without surprises or unexpected questions. (Average)
- Less difficult than expected but on the other hand I expected it to be insanely difficult so this was a good thing. (Average)
- I can say easy but, it is easy if you have studied a lot during the course. (Easy)
- I was well prepared, so it was easy for me (Easy)
- The oral exam could have been a bit more difficult. (Easy)

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

20 svarande

Very good	6		30%
Good	12		60%
Average	1		5%

Poor	1	5%
Very poor	0	0%

- *Everything felt well organised and under control by the course responsible.* (Very good)
- *All information was clear.* (Very good)
- *Crystal clear course description.* (Very good)
- *Some of the things in the course description weren't covered in the lectures. An example is the Weyl equation (unless I missed that lecture).* (Good)
- *Few time to digest topics, total absence of exercise sessions that would indeed be very important to understand the subject!* (Poor)

What is your opinion about the course literature?

20 svarande

Very good	2	10%
Good	6	30%
Average	5	25%
Poor	6	30%
Very poor	1	5%

- *It is good and rich. Some mathematical steps are omitted and it is difficult to demonstrate some of those steps. The physical part can be expanded too.* (Good)
- *It is a good summary of everything that is learned in the course but it lacks some of the detail that a student new to the topic needs.* (Good)
- *Reading multiple books helps. I recommend using both Peskin and Schröder and the lecturer's own book.* (Good)
- *I would have wanted more concrete examples of where the theory is applied in nature. Also, the book was very similar to the lectures, which was good in the sense that you could get a good idea of what was particularly important, but also negative in the sense that it provided no extra resource if the lecture was difficult to comprehend.* (Average)
- *None of the recommended books worked very well for me alone, but they worked well together. I used Tommy's book throughout the course along with Greiner and Peskin & Schroeder for the first and second part respectively. I also used Schwartz Quantum Field Theory and the Standard Model, which was not recommended, but which I found to be quite good.* (Average)
- *I very often felt that what I was looking for wasn't in the book, or wasn't enough details for me to be able to understand it.* (Poor)
- *I read the whole book, but many chapters do not give enough tools to be able to solve the hand in problems. Additional literature is indeed indicated at the end of each chapter, but it takes a great deal of time to be able to find the right source in order to understand the topic.* (Poor)
- *I think the course litterature was far to dense mathematically with little to none physical intuition. It was sometimes hard to follow*

conclusions drawn. (Poor)
- The course book was rarely self-contained, and the consulting of other sources was very often a matter of understanding what the course book was trying to say. (Poor)
- I found Peskin & Shroeder to be more appropriate for me, different taste I suppose. (Poor)
- I think that the course material is useful for someone that is already familiar with the subject, since everything is contained in it. Unfortunately, I think the best way to describe the literature here is that it feels like trying to learn a subject from its formula collection. (Very poor)

How did the lecture format (live on blackboard + recorded) work?

20 svarande

Very well	8	40%
Well	11	55%
No opinion	1	5%
Poorly	0	0%
Very poorly	0	0%

- I miss the live lectures but this method should be implemented also after the end of the pandemic. It is very useful to go again through lectures when some aspects are not clear or you simply missed something. (Very well)
- Very useful with repetition. (Very well)
- I very much appreciated the recordings as it was very useful to be able to go back and rewatch specific parts of the lectures. (Very well)
- It was great to be able to go back and look at the reccordings again if something was unclear. (Very well)
- For me it was really good to have the recorded lectures to go back to (Well)
- It was good to have the possibility to go back and watch old lectures. However, since no student participating via zoom was to be recorded anyway, why not record the lecture externally with e.g. a videocamera or phone? Maybe this would have alleviated a major downside of zoom-lectures, namely the pour video quality which sometimes made it difficult to read the board, at least in the recording. (Well)
- Having the possibility to ask questions anytime would be appreciated, but I understand that the editing would then be too time-consuming. (Well)

How were the lectures?

20 svarande

Very good	4	20%
Good	8	40%
Average	4	20%
Poor	4	20%
Very poor	0	0%

- *The rhythm of the lecture is good, sometimes fast but it is good to keep the attention and focus high.* *(Good)*
- *I would have wanted more focus on why we were doing things (like the physical motivation), and where things come from and why they are defined the way they are.* *(Average)*
- *Since the amount of theory is quite large in this course, it felt like focus was to bulldoze through the theory, and not so much on the fundamental understanding of it. The course itself is very interesting, but it is easy to get put off by the bulldozing of material.* *(Average)*
- *There were too many calculations with too few explanations what we are doing and why. I would have appreciated more conceptual discussion.* *(Poor)*
- *Even when I was on track, I never understood a single lecture, due to the condensation of extremely difficult topics inside single lectures. Regularization and renormalization were explained in barely 45 minutes.* *(Poor)*
- *A lot of content was covered in each lecture, and piecing together the central message was often difficult. The two last lectures are the exception - by far the best lectures in the entire course.* *(Poor)*
- *The spontaneous discussion during the lectures was missed.* *(Poor)*

Would it be useful to have separate discussion sessions in the course?

20 svarande

Yes	11	55%
Neutral - no opinion	8	40%
No	1	5%

- *Sometimes students prefer not to ask the professor some doubts because of a lack of study. But then it would be great to discuss during the course about some questions.* *(Yes)*
- *At least a few sessions where the teacher takes up the central aspects of the course and how to think about them and what their importance is. A few calculations of the problems from the book would have been helpful.* *(Yes)*
- *Yes, especially if the ability to ask questions during lectures is restricted.* *(Yes)*
- *I think that this course actually needs exercise sessions rather than discussion sessions.* *(Neutral - no opinion)*
- *I do not think discussion sessions are necessary. If something were to be added to the course it should be more detailed instructions on how*

to calculate things using what we learned. (No)

Please enter any further (non-covid-19-situation-related) comments on the course below.

- The course is intense. The topics are difficult to cover in details in this reduced time interval. Maybe, some lessons in addition would be better for students. I also think that sometimes the exercises (even if they require a previous study of the topics) stole time to self-study the chapters.
- The course needs to be done in more than one period, otherwise topics need to be reduced. Exercise sessions really need to be added.
- I would have liked more concrete examples of where the theory can be applied in nature and why it is needed. Sometimes I felt as though I was learning abstract facts verbatim, where it was not clear how it corresponded to an external reality. I believe this is the biggest area of possible improvements for this course, since everything else worked well, apart from the relatively minor issues listed in the other questions.
- I would say this course totally delivered on what the description was. The professor was exceptionally knowledgeable of the material and with the comments and explanations that he gave during the lectures it made me obtain a deeper understanding of the material. The home assignments were really interesting and challenging at the same time which made me get a good grasp on the mathematical formalism and the physical meaning. The oral examination was perfectly executed and the professor was really friendly, in the end it felt to me as just having a conversation on the subject. The only part of the course that I didn't enjoy as much were the quizzes, they were not hard since just by following the lectures you were able to answer the questions. However, in a course like this I think it would have been better to just have 6 home assignments, maybe 3 of them being easier (just a basic understanding of the lectures just like the quizzes) and 3 of them being harder (just like part 2 of each home assignment).
- I have learnt much!
- I would have highly appreciated a list of recommended exercises WITH SOLUTIONS. This is an advanced topic and it is difficult to verify one's solutions online.
- I would prefer more focus on the ideas behind the equations and intuition especially in the last few topics.
- It would have been good if some excercise-sessions where held to just go trough some examples and calculations again. Maybe it would be enough with 3 or 4 sessions.

Please enter any further (covid-19-situation-related) comments on the course below.

- In person lectures are always better to be processed.
- The absence of covid seriously hindered my possibility to interact with the professor. If lessons had been done in class I would have

maybe asked more questions.
- The lecture format with the blackboard and the recorded lectures was perfect. This course has adapted really well in view of the covid situaton.
- I did not find that covid impacted the course significantly.

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