

QFT

(Quantum Field Theory)

Level 4 Theoretical Physics
Course - PT4.4

Tim Evans (Theory)



Web Site
<http://bit.ly/2ylihNN>

Background

5th October 2018

QFT is essential to understand nature at smallest scales. The success of the standard model of particle physics in matching the high energy physics experimental results from CERN and similar accelerators requires QFT. For cosmology, QFT is essential in trying to go beyond the standard model to see if we can see echoes of new physics in modern measurements. However we should not forget that the Higgs mechanism, so greatly heralded when the Higgs boson was found at CERN in 2012, is behind superconductivity, something understood theoretically since 1957. So QFT also plays an important role in condensed matter systems such as ultra cold atom condensates.

Key Facts

- Lecturer: Tim Evans (Theoretical Physics).
I lectured QFT for the first time in the Autumn of 2014. I do not expect any significant changes for the Autumn 2018 course though the course is continually evolving as I respond to feedback from SOLE, the way students answered the exam, to individual student comments and my own impressions. I lectured QTM (Quantum Theory of Matter) from 2009-2013 and gave Unification and Group Theory before that. All these topics have links to and overlaps with this QFT course.
- Level 4 theory course — you need to be very good at maths.
- Term 1 (Autumn)
- Prerequisites: FQM (Foundations of Quantum Mechanics), ACP (Advanced Classical Mechanics)
- 26 lectures (Autumn term) + 1 Revision lecture (Summer term)
- Office Hours: Twice a week, Mondays at 12 noon and Thursdays at 9am, in my office, Huxley 609.
- Five Rapid Feedback classes.

Autumn 2018: Presentation by PhD student Lucas Wallis. Check your timetable but at time of writing the first rapid feedback will be at 13.00 on Thursday 11th Oct. in LT2. After that, they are in LT2 on alternate Fridays (even weeks) at 17.00.

I will nominate two or so questions. If you want written feedback, hand in the answers to the nominated questions only to a box provided in undergraduate office by noon Wednesday before the presentation with the exceptional deadline of noon on Monday 8th Oct. for the first session. These are corrected by the postgraduate who provides the individual written feedback. This

does not contribute to the course assessment in any way though a rough mark may be given as part of the feedback. The postgraduate also presents a commentary on the problems in a fifty minute lecture.

- **Six Problem Sheets.**

These will contain both questions used for rapid feedback and addition questions. Questions graded (essential, recommended, optional/hard) to indicate importance and to help time management. Answers provided.

- **Assessment.** A standard two hour exam in May.

- **Supporting Material.**

I do not have typed notes for my whole course but I provide a copy of my hand written notes at the end of the course though these are of limited quality and use. I provide thirteen summaries of key aspects which, along with extensive answers to questions, now provide over eighty pages of typed material from me. There are also the free QFT notes by David Tong (see below) are an excellent resource for this course.

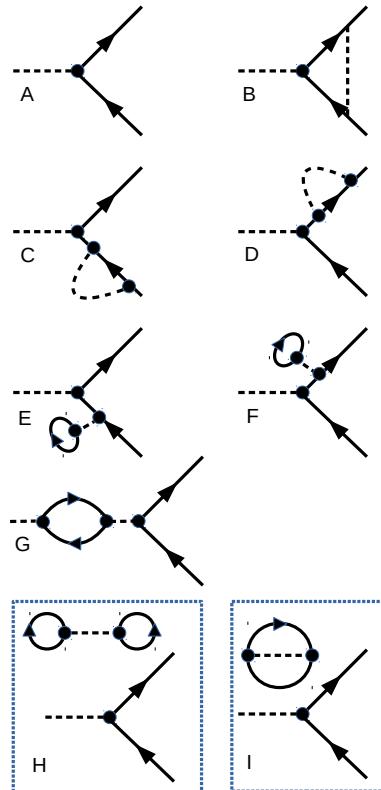
All my course material can be inspected by anyone. It is available from the QFT section of the Theoretical Physics web site (open to all). For a short link try <http://bit.ly/2ylihNN>. The VLE Blackboard system will not be used.

The course follows closely the approach set out in a set of free notes by David Tong, *Quantum Field Theory*, [<http://www.damtp.cam.ac.uk/user/tong/qft.html>]. I try to keep the same notation as much as possible. I also follow much the same path through the topic though I sometimes take a slightly different route to reach an answer. There are endless books on QFT and I recommend some on my QFT Course Bibliography and on the library's QFT course bibliography.

Objectives

To introduce students to basic quantum field theory. The specific aims are that at the end of the course students will be able to:

- provide some motivation for the use of fields to describe fundamental particle physics.
- describe a scalar (spin zero) particle in terms of a classical field theory.
- link symmetry (U(1) phase symmetry only) and conserved charges for a complex scalar quantum field, and to understand this is as an example of Noether's theorem.
- quantise a free scalar field theory using canonical quantisation.
- derive Feynman diagrams and use them to study the scattering of particles.
- give a basic examples of renormalisation.



Complementary Courses

- **Unification.**

Unification covers the standard model of particle physics using advanced quantum field theories. Unification will only consider the classical version of the theories. QFT will leave you with an understanding of what is involved in doing the full quantum calculations in the standard model of Unification but you would require a couple more courses to be able to do such calculations.

- **Advanced Particle Physics (APP).**

QFT is the key tool used to calculate all the physical quantities measured in high energy physics experiments such as those at CERN. By the end of this course students will only just about be able to calculate the simplest examples in approximate (or toy) models rather than measurable in realistic models. APP will though give you a broad overview of one of the most important applications of QFT (though not the only one) and APP matches the particle physics context of this QFT course. However most of the expressions used in APP will still be beyond students at the end of the QFT course. To reach these more realistic expressions takes a whole MSc (such as QFFF at Imperial).

- Anything with **Quantum** in the title.

Many of the ideas and some of the algebra will reappear in different contexts and with a different emphasis in several other quantum courses. This is likely to reinforce and enhance your understanding of several ideas in the QFT course.

Prerequisites

The two official prerequisites are FQM (Foundations of Quantum Mechanics) and ACP (Advanced Classical Mechanics). I will also assume that you have done the Maths Methods course of year 2.

FQM. You need to be able to handle operators in general. You must be able to be able to deal with commutators and you will need to be fluent when handling expressions where the order of items matters. Creation, annihilation operators, their states (part of a Fock space) and the associated Dirac notation (e.g. $\langle 0|\hat{a}^\dagger \hat{a}|0\rangle$) are central to QFT so you will need to be experienced with these. The first QFT problem sheet (see web site) is basically revision of such core concepts, I do not cover these ideas in lectures and will assume students already know them. If you can do PS1 then you can probably handle the quantum aspects of the QFT course.

ACP. We will work with Hamiltonians and Lagrangians, classical and their quantum equivalents, and the concept of conjugate momentum so you need to be familiar with these. In fact we will only work with a small number of variations. The course will be almost entirely relativistic. In practice you just need to be familiar with four-vectors, mostly four-momenta such as $p^\mu = (E, \mathbf{p})$ and coordinates $x^\mu = (t, \mathbf{x})$. You need to be familiar with the notation $p.x = p^\mu x_\mu$ and that this notation describes an object which is invariant under Lorentz transformations (a “Lorentz scalar”). However the notation will then carry all we need from special relativity and we will focus on QFT rather than dwelling further on the many other implications of Lorentz symmetry.

Maths. This course contains many long algebraic expressions and you need to be good at handling such expressions. I would be very surprised if you were taking QFT but you had not done every optional Maths course you could, not because you need all that material but because it suggests you do not have the ability to handle a lot of maths. One area we need is integration in the complex plane (residues, poles and all that). There is one main example in the middle of the course (four propagator variants). To analyse and evaluate the final expressions produced from Feynman diagrams does require extensive use of complex analysis but that is for your next QFT course.