Phys 3765 Advanced Quantum Mechanics -- QFT-I Fall 2012

Instructor:
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class meets Tuesday and Thursdays, 2:30-3:45, 316 OEH

Office Hours: Tuesday and Thursday, 3:45 - 4:45.

Introductory Texts:
(*) = required, (+) = strongly recommended

- F. Mandl and G. Shaw, *Quantum Field Theory*
- (*) Peskin and Schroeder, *An Introduction to Quantum Field Theory*
- F. Gross, *Relativistic Quantum Mechanics and Field Theory*

Reference Texts:

- (+) Donoghue, Golowich, and Holstein, *Dynamics of the Standard Model*
- Itzykson and Zuber, *Quantum Field Theory*

Marking Scheme: final = 0.4 take home exam + 0.6 assignments OR 1.0 assignments ...

Prerequisites:
You should be adept at quantum mechanics. Exposure to high energy physics, nuclear physics, tensors, relativistic EM, classical field theory, and quantum many-body physics would be very helpful but is not required. Taking the nuclear and high energy physics course is strongly recommended.

Assignments:

- asst 0: read "Notes for a History of QFT" (linked below)
- asst1: EM Fields and Ladder Operators due Sept 13.
- asst2: The Photoelectric Effect due Oct 2.
- asst3: Klein-Gordon Preliminaries due Oct 11.
- asst4: Introduction to Feynman Diagrams due Oct 23.
- asst5: Renormalisation Preamble due Nov 1
- asst6: phi^3 Theory at one loop TBD
- asst7: Renormalisation group, two loops, and coupling flow, due Dec 13.

Syllabus QFT-I:
We will be covering essentially all of Peskin and Schroeder over the two terms of this course. This text, like most other QFT texts, concentrates on teaching the methods of quantum field theory. There are precious few applications. Thus it is important that you take Nuclear and Particle Physics. Donoghue et al. is also a wonderful resource with many applications and advanced topics. I will supplement the material of Peskin and Schroeder with

- historical introduction
- the particle+wave picture
- the Lamb shift
- renormalising phi^4 theory, the running coupling, relating different renormalisation schemes
- issues with the path integral
- Schwinger-Dyson equations
- Bethe-Salpeter equation

- Young tablueaux
- the strong CP problem
- baryogenesis
- effective field theory
- problems with the Standard Model

An important technical point: Peskin and Schroeder introduce the Dim Reg renormalization in an ad-hoc way, we will follow the traditional approach of introducing the scale via the coupling. We will also use a simpler and more direct method to obtain the beta function than is used in the text.

Time constraints will force us to cover many of these topics superficially. Quantum field theory is an *enormous* topic; this course only gets you started. There is no second course, so you must read, read, read to learn more. I have assembled the following files to help you in this regard.

Quantum Field Theory Texts

- Dyson QFT Freeman Dyson's classic QFT notes from Cornell, 1951
- Coleman QFT Sidney Coleman's QFT notes from Harvard, 1985

Historical Articles

- The Making of the Standard Model S. Weinberg, history from a participant
- Notes for a History of QFT S. Weinberg, sketch history of QFT
- What is Quantum Field Theory? S. Weinberg

Classic Articles

- The Electromagnetic Shift of Energy Levels Hans Bethe, 1947
- Space-Time Approach to Non-Relativistic Quantum Mechanics, Richard Feynman, 1948
- The S Matrix in Quantum Electrodynamics, Freeman Dyson, 1949
- Space-Time Approach to Quantum Electrodynamics", Richard Feynman, 1949
- Quantum Electrodynamics at Small Distances M. Gell-Mann and F. Low, 1954
- Diagrammar G. 't Hooft and M. Veltman, 1973

Review Articles

- Quantum Theory of Radiation E. Fermi, 1932
- Quantum Chromodynamics W. Marciano and H. Pagels, 1977
- Strong Dynamics and Electroweak Symmetry Breaking Hill and Simmons, 2003
- A Primer on Functional Methods and the Schwinger-Dyson Equations, E. Swanson, 2010
- How to Renormalise the Schroedinger Equation, P. Lepage, 1997 (a wonderful introduction to effective field theory)

Newer Important Articles

- Effective Action for Composite Operators Cornwall, Jackiw, and Tomboulis
- A Relativistic Equation for Bound States Bethe and Salpeter
- Symmetry Behavior at Finite Temperature Dolan and Jackiw
- Radiative Corrections as the Origin of Spontaneous Symmetry Breaking Coleman and Weinberg
- Introduction to Second Quantization
    - Why Quantum Field Theory?
    - Second Quantization of the photon field
    - matter and light: nonrelativistic electrons, protons, and photons. Fermi's Goldon Rule, gauge invariance, black body radiation, Kramers-Heisenberg formula, Compton scattering, Rayleigh scattering, Thomson scattering, Coulomb gauge, photoelectric effect
    - first glimpse of renormalisation: the Lamb shift a la Bethe
- Spin-0 Fields

    - Klein-Gordon: propagators, causality, Feynman prescription, Noether's theorem, spectral function, energy-momentum tensor
    - interaction picture, S-matrix, Gell-Mann--Low theorem, Wick's theorem, Feynman rules, connected diagrams, scattering theory, decays, Mandlestam variables
    - another glimpse of renormalisation (tadpole diagrams)
- Spin-1/2 Fields
    - Dirac: spin statistic theorem, Lorentz invariance, bilinear currents, discrete symmetries, Diracology, trace theorems, helicity, chirality, the Foldy-Wouthuysen transformation
    - quantising: anticommutators, fermion propagator, chiral invariance, Feynman rules, the NJL model, fermion-scalar interactions, nonrelativistic interactions, nuclear physics (pi-N-N interaction)
- Spin-1 Fields
    - Electromagnetism: relativistic formalism, gauge fixing, Gupta-Bleuler presciption, Feynman prescription
    - quantising: photon propagator, Ward-Takahashi identities, infrared divergences, Feynman rules, P and C invariance, Yang's theorem, Furry's theorem
    - applications: Moeller scattering, Bhaba scattering, Klein-Nishina formula, decays, positronium decay, crossing symmetry, decay constants, B decays
- Renormalization I
    - fractals
    - an example from quantum mechanics: scattering via a delta-function
    - phi^4 at one loop order: divergent diagrams, regularization, renormalization schemes, renormalization group, running coupling, fixed points and the beta function, Wick rotation, dimensional regularization, lambda(MS)/lambda(MS-bar)