Cornell University

Department of Physics

Physics 651 August 25, 2006

Fall 2006
Relativistic Quantum Field Theory I

Course Information

Motivation: Relativistic Quantum Field Theory provides an indispensable theoretical tool for understanding the properties of elementary particles and their interactions, forming the backbone of the immensely successful "Standard Model" of particle physics. In addition, it has a variety of applications in astrophysics and cosmology, and related theoretical methods are widely used in condensed matter and atomic physics.

Who Should Take This Course: The target audience is graduate students planning to do research in any area of theoretical physics, as well as those interested in joining LEPP experimental groups. (Of course, anyone else who is curious and brave is welcome too!) Students who intend to specialize in high-energy theory should pay special attention to this course, and should plan to take the second part of the QFT sequence, Physics 652, offered in Spring.

Prerequisites: A strong undergraduate Physics and Math background, as well as graduate-level Quantum Mechanics and E&M. Familiarity with the following topics is especially important:

- *Classical Mechanics:* Lagrange formalism, Hamiltonian formalism, Noether theorem.
- *Special Relativity:* Lorentz transformations, 4-vector notation and calculus.
- *Quantum Mechanics:* Heisenberg and Schrodinger pictures, harmonic oscillator including creation/destruction operators, angular momentum. Some familiarity with non-relativistic scattering theory would be useful.
- *Mathematics:* Fourier transforms, contour integration, variational calculus, distributions (Dirac δ-function, θ-function, ...) and special functions.

Lecturer: Maxim Perelstein, 334 Newman Hall, x5-4118 (`mp325@cornell.edu`);
Office hours: Monday 3-4 pm, or by appointment

Graders:
Naresh Kumar (`nk236@cornell.edu`); Dan Wohns (`dfw9@cornell.edu`)

Class Times and Locations:
Lectures: MW 8:40-9:55 am, Rock 110

Course Web Page:
http://www.lepp.cornell.edu/~maxim/P651/

Required Text: *An Introduction to Quantum Field Theory*, by M. Peskin and D. Schroeder. We will cover most of Chapters 2–7, and some of Chapter 9, in this course. A variety of topics from the remainder of the book will be covered in Physics 652.

Optional Texts:

- *Quantum Field Theory in a Nutshell*, by A. Zee. "The purpose of Zee's book is not to turn students into experts — it is to make them fall in love with the subject," according to the *Physics Today* reviewer. This book is actually fun to read! It is a great complement to (but unfortunately not a substitute for) a more formal textbook like P&S. Highly recommended.

- *Quantum Field Theory*, by L. Ryder. A gentle, but rigorous, introduction.

- *The Quantum Theory of Fields*, by S. Weinberg. A monumental three-volume work by one of the greatest masters of the subject. A bit too much for a typical novice, but there are exceptions.

- *Field Theory: a Modern Primer*, by P. Ramond. An insightful, if somewhat idiosyncratic, introductory text.

Homework: There will be one problem set each week. The problem sets will be posted on the course web page at least a week before the due date, and have to be turned in before the beginning of lecture on the due date (Wed each week). The homeworks will be graded by the grader and returned to students along with solution sets. Problem sets and reading assignments are an essential part of the course and should be taken very seriously. Each student in the course is expected to abide by the Cornell University Code of Academic Integrity.

Final Project: There will be a mandatory final project at the end of the course. There will be no midterm or final exams.

Course Grades: This class is S/U only. The S grade requires at least 50% of the credit on the homeworks **and** at least 50% credit on the final project.

Probable Syllabus

- Why field theory? Relativistic quantum mechanics and causality

- The Klein-Gordon field and harmonic oscillators. Quantization of the KG field. Space-time interpretation of fields and causality.

- Symmetries. Noether's theorem. Conservation laws.

- Lorentz invariance and representations of the Lorentz group. Weyl and Dirac fermions.

- Dirac Largangian and Dirac equation. Quantization of the Dirac field. Particles and antiparticles.

- Discrete symmetries of the Dirac theory.
- Interacting fields: rules for constructing Lagrangians. Relevant and irrelevant interactions.
- Cross sections, decay rates and the S-matrix.
- Perturbation theory. Correlation functions. Wick's theorem.
- Feynman diagrams and Feynman rules in φ^4, Yukawa theories and Quantum Electrodynamics.
- Elementary processes in QED: Electron-positron annihilation. Compton scattering. Crossing symmetry.
- Radiative corrections: Calculation of 1-loop diagrams. Interpretation of infrared and ultraviolet divergences. Mass and wave-function renormalization in QED. LSZ reduction formula. Effective charges and running couplings. Optical theorem.