

## Physics 218: Advanced Quantum Field Theory

Winter, 2004 Instructor: Michael Dine

**Course Description:** Last quarter, in Physics 217, we mastered the basics of quantum field theory and the method of Feynman diagrams. We acquired a good working knowledge of the basics of quantum electrodynamics, as well as simple scalar field theories and theories with Yukawa couplings of scalars to fermions. We learned to quickly compute tree level cross sections, and acquired some understanding of the various divergences which arise in one loop in both theories.

There are many ways we can go beyond this in this course, and we discussed some of these in our opening session. I think we are agreed on a few points:

1. We will want to introduce the Standard Model, and sufficient theoretical tools to do basic calculations.
2. We want to do at least some aspects of renormalization theory and the renormalization group.
3. There are a number of other topics we might want to consider as time permits. These include: critical phenomena, group theoretic issues in field theory, anomalies, and perhaps topics such as supersymmetry (though Professor Haber will cover supersymmetry in his course in the spring).

Our path, at least at the beginning, is clear. We will start by introducing the Path Integral. This is essential if we are to treat the quantum mechanics of the Standard Model (specifically, the quantum mechanics of Yang-Mills theories). Then we will develop Yang-Mills theories (non-abelian gauge theories), first classically and then quantum mechanically. At this point, we will have encountered all of the possible renormalizable quantum field theories. We will then turn to a number of computations in these theories: asymptotic freedom of pure Yang-Mills theory and its implications (QCD), and the Higgs mechanism, necessary to understanding the electroweak interactions. In the course of the loop computations, we can discuss the systematics of renormalization and some aspects of the renormalization group.

After this, we will have to make decisions. Anomalies might be a natural choice, given all of the computational machinery we will have developed. The same, however, could be said of critical phenomena.

Finally, in addition to homework sets, I would like each of you to prepare a final project. We should decide on these by the middle of the course. We will present this the last week and during the exam period. This will give us an opportunity to delve into some of these other topics. You should plan to devote some time to

these, and I will be available to help you, both with the actual preparation and also in locating resources.

**Note on the texts:** The principle text for the course will be Peskin and Schroeder's "Introduction to Quantum Field Theory." This text is, in my view, probably the best field theory text which presently exists. This is particularly true for the topics we will study this quarter. The treatment of renormalization is close in spirit to that of Wilson (esp. chapter 12). We will cover chapter 9 on the path integral method, parts of chapters 15 and 16 on non-abelian gauge theories, chapter 10 to understand how renormalization works beyond one loop order, and parts of chapters 12-13 on the renormalization group and critical phenomena – giving us both a deeper understanding of the significance of renormalization and allowing us to use the renormalization program as a powerful tool. You will probably want to supplement the reading with others. For example, you should review Shankar's discussion of path integration, or that of some other quantum mechanics or quantum field theory text (e.g. Ryder). I have put the book, "Path Integrals and Quantum Mechanics," by Feynman and Hibbs, on reserve. This contains many path integral exercises. I will make other suggestions and provide handouts from time to time. Other books which treat some of these more advanced topics well include Weinberg's three volume set on field theory, and Lowell Brown's text. The various other texts on reserve for 217 will be on reserve again.

**Homework, exams,etc:** We will have approximately five rather demanding homework sets, as well as the final project mentioned above.

### (*Very*) Tentative Schedule

#### Warmup: Read PS, chapter 8.

Jan. 6: An introduction to the Feynman path integral.

Jan. 8, 13: The functional method in field theory, including the quantization of QED and the quantization of fermions.

Jan. 15,20. Introduction to non-abelian gauge theories. (PS chapter 15, chapter 16 through section 3.): Classical theories, and Feynman rules. (**Class Jan. 15 will have to be rescheduled as I have to be in Washington that day**).

Jan. 22. Renormalization: The Counterterm Method. (Section 10.1-10.3).

Jan. 27, 29: Asymptotic Freedom of QCD (applying the counterterm method). (section 16.5)

Feb. 3,5,10: The renormalization group. Starting with Wilson's approach to the renormalization group, we will derive the renormalization group equations, and understand our QCD results in this context.

Feb.12, 17: Spontaneously Broken Gauge Symmetries and the Higgs Mechanism (Chapter 20). The full Standard Model

Feb. 19,24: Quantization of Spontaneously Broken Gauge Theories; survey of some radiative corrections in the Standard Model.

Feb. 26, March 2,4,9,11: Additional topics. These may include: critical phenomena (chapter 13), anomalies (chapter 19), the effective action and the background field method (chapter 11 and 16.6), more detailed QCD analyses (particularly deep inelastic scattering, other high energy/short distance projects). Also possible are supersymmetry and its phenomenology or applications to study of field theory phenomena.