PHY 621, MWF 11-11.53 in P129.

ADVANCED QUANTUM FIELD THEORY I

Peter van Nieuwenhuizen and George Sterman.

This is part I of a two-semester course. It has been taught for a long time by PvN , but this time GS will join with a series of lectures on QCD. The class is both advanced and basic. It treats topics that are usually not reached in a two-semester course on ordinary quantum field theory although graduate students are supposed to know this material. However, we derive everything from scratch and in detail. For that to be possible we hand out typed notes .The prerequisites for this class are the material of a course in ordinary quantum field theory: one-loop Feynman diagrams, dimensional regularization, quantization of nonabelian gauge theories with gauge fixing term and ghost action. We shall use BRST methods; these were discussed last year, but the material is easy to learn and we shall provide notes for those who have not seen this before. We shall also encounter a few times supersymmetric (susy) quantum field theories, but we do NOT assume any knowledge of susy; rather, we derive the results we need in class (for those who have not seen susy before, this is a way to learn it).

There are weekly homeworks and a written and an oral exam at the end of the class. Some students do better on oral exams, others on written exams. The better of the two exams will count for 2/3 of the grade; this way everybody gets a chance. Office hours are after class. The list of topics is as follows:

1.Path integrals and Feynman graphs in quantum mechanics. Since there are no divergences in quantum mechanics (at least for linear sigma models), questions such as the boundary conditions in path integrals on a finite or infinite time interval can be settled by explicit calculations in closed form. We consider first flat time and then instantons (the kink solution in Euclidean time) and Feynman rules and Green functionsin background fields. We apply this to study the effect of multi-instantons on tunneling. We also discuss the WKB approximation to path integrals, and the decays of metastable vacua leading to phase transitions. Later in the class the same issues will arise in quantum filed theory where, however, similar results in closed form are not available.

2.Renormalization of nonabelian gauge theories to all loop order. Using BRST symmetry we derive a functional equation for the divergences in proper graphs, and then solve this equation perturbatively. We first consider unbroken gauge theories (such as QCD), and then spontaneously broken gauge theories (Higgs models).

3.Instantons. The winding number is introduced and evaluated, and moduli and and zero modes are explicitly computed, both for gauge fields and for bosonic and fermionic matter in an instanton background. The measure for bosonic and fermionic collective coordinates is derived. The exact beta function is constructed for some susy field theories. Then some applications are discussed: large instantons and the Higgs effect, tunneling and theta-vacua, the strong CP problem, the U(1) problem, and instantons at finite temperature.

4.Anomalies. First the V-A basis and the chiral basis are introduced, and one-loop anomalies in triangle graphs are computed with a variety of regularization schemes, including ordinary dimensional regularization, and regularization by dimensional reduction. Next we show that anomalies ruin renormalizability and unitarity. Then the consistency conditions for anomalies are used to derive the Bardeen anomaly (which contains also the anomalies of box and pentagon diagrams). We next derive the Wess-Zumino term ("the integrated chiral anomaly") and discuss its phenomenological successes. Then we explain the difference between covariant and consistent anomalies, and construct the descent equations (which give both, and more).

5. Infrared aspects of perturbation theory. The infrared behavior of Green functions and scattering amplitudes is a central issue in applications of quantum field theory at high energies, and is intimately connected to the analytic structure of operator matrix elements. We'll start with general methods that identify the origins of singularities in momentum or coordinate integrals in complex space, and develop methods to evaluate the strength of these singularities. In this connection, we will encounter some of the special features of massless gauge theory amplitudes. We'll go on the show how these ideas are applied to cross sections, and why infrared singularities cancel in cross sections that are defined in terms of energy flow, leading to the phenomena of jets. Finally, we'll introduce the ideas of factorization, evolution and resummation.