Advanced Quantum Field Theory

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PHYS 621

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This class is for students who have completed a standard class in quantum field theory. The class is both advanced and basic. It is advanced because we discuss topics which are usually not reached in a two-semester class due to lack of time although graduate students in particle physics are supposed to be familiar with them. However, we discuss these topics from scratch and in detail. This year we have added a discussion of some aspects of effective field theory. The list of topics is far too long to teach in one semester, so we will continue next fall with other advanced topics. There will be both a written and an oral exam at the end of the class, but students may also make special studies of particular topics after consultation with me. Typed notes of a forthcoming book will be distributed.

1. **BRST quantization** of non-abelian gauge theories. Review and brief history of quantization of gauge field theories (intended for students who have not had much experience with ghost actions). BRST symmetry. Nilpotency and auxiliary field. Ward identities for connected and proper graphs. All-order proof of renormalizability of QCD and Higgs models. One-loop checks using dimensional regularization.

2. **Anomalies**: One-loop triangle, box and pentagon anomalies. Gauge anomalies ruin renormalizability and unitarity. Cancellation of anomalies in the Standard Model. Anomalies in the $B - L$ symmetry. Anomalies in path integrals from Fujikawa's method. Consistent and covariant anomalies. Descent equations. Higher-loops and the Adler-Bardeen theorem.

3. **Instantons**: Classical one- and multi-instanton solutions. Winding number. Bosonic zero modes and collective coordinates. Index theorem. Fermionic zero modes. Path integral measure for zero modes. Tunneling. θ-vacua. The $U(1)$ problem. Large instantons and the Higgs effect. Finite temperature instantons.

4. **Solitons**: The classical kink, vortex and monopole solutions. Supersymmetric solitons and the classical BPS bound. Quantization of solitons and zero modes. Quantum corrections to the BPS bound. Index theorem for spectral densities. Duality between point particles and solitons.

5. **Effective field theory**: Nonlinear realizations of symmetries and coset models. Effective actions with $SU(2) \times SU(2)$ and $SU(3) \times SU(3)$ symmetry. Wess-Zumino effective actions. Homotopy. Skyrme model. Renormalization of composite operators, mixing and anomalous dimensions.

Next fall we shall continue with: background field method, supersymmetry, unitarity from the cutting rules, renormalization group and β functions, Hamiltonian quantum field theory and Matthews' theorem, Dirac formalism and BV antifield formalism, dimensional reduction and evanescent counter terms.