Outline of QFT 2 course

Extension section

Here we cover some of the important topics that were not covered in the first semester. These include several functional methods and also techniques with fermions.

Extension 1 – Very quick review, vacuum polarization via Feynman rules, quick review of Path Integral formulas, vacuum polarization via functional techniques, functional differentiation again.

Extension 2 – Perturbation theory via functional derivation, completing the vacuum polarization example, the determinant of a differential operator det $(D^2 + m^2)$, det = exp tr ln identity, integrating out the scalar field, renormalization and effective Lagrangian.

Extension 3 – Heat kernel method, Fermion path integral, Functional differentiation with anticommuting sources, Grassmann numbers, Spin statistics theorem, Dirac algebra, ordering in Feynman diagrams, gauge invariance example.

Extension 4 – Chiral fermions, left and right fields, Majorana mass, spin sums for fermions and photon, traces of gamma matrices.

Extension 5 – Practical group theory, SU(2) and SU(N), representations and transformation rules, constructing invariants, extracting predictions

Gauge Theory section

In this section we extend the treatment of gauge symmetry to nonabelian groups, explore some gauge theory features and give a full quantization of Yang-Mills gauge theories

Gauge theory 1 – Nonableian gauge symmetry, the Yang Mills lagrangian, path integral quantization, problem with propagator, simple example of factoring out symmetry, constraining the path integral.

Gauge theory 2 – Review of path integral quantization, QED example, covariant gauges, Fadeev-Popov trick, ghosts, Yang Mills example, Feynman rules for Yang Mills.

Gauge theory 3 – running coupling in QED, 1/epsilon determines logs, charge renormalization in Yang Mills, vacuum polarization, oddities of dimensional regularization, calculating casimirs.

Gauge theory 4 – ghost and fermion contributions to running coupling, the overall beta function, matching across mass thresholds, scheme dependence, higher orders.

Gauge theory 5 – g=2 from Dirac equation, calculating g-2 and the vertex correction.

Effective Field Theory Section

I treat the idea of effective field theory both in general and by use of the specific case of the linear sigma model.

Effective field theory 1 – What is effective field theory, locality, QED effective Lagrangian, the energy expansion, linear sigma model, a low energy calculation and its effective Lagrangian

Effective field theory 2 – the exponential representation, recalculating the scattering amplitude, path integral connection, integrating out at tree level, start of matching.

Effective field theory 3 – Integrating out scalar, heat kernel, general form of effective L, which parameters to use, matching the effective theory and the full theory.

Effective field theory 4 – Power counting, Weinberg theorem, measuring vs matching, Rules of EFT, relevance of sigma model, explicit symmetry breaking, Wilson and EFT.

Effective field theory 5 – The operator product expansion, weak interaction example, the background field method, φ^4 example, heat kernel, perturbative expansion, background field renormalization of the sigma model.

Anomalies Section

I treat symmetries and anomalies using primarily a path integral approach

Anomalies 1 – currents in path integrals, path integrals and symmetries, scale invariance in the Standard Model, The trace anomaly, calculating the path integral jacobian

Anomalies 2 obtaining the trace relation, Feynman diagram approach, interpreting the trace anomaly, the simplest derivation via running charge, axial U(1) problem, starting the chiral anomaly calculation.

Anomalies 3 shift of integration variable, the pi to 2 gamma story, anomalies and gauge currents,

Standard Model Section

This is a very brief tour through the structure of the Standard Model

Standard Model 1 quantum numbers, U(1) ambiguity, anomaly conditions, hypercharge assignments

Standard Model 2 – Adding the Higgs, Gauge boson masses, Gauge currents for fermions, Math: doublet = anti-doublet, Yukawa couplings

Standard Model 3 – Diagonalizing mass matrices, Neutrino masses and see saw mechanism, diagonalizing neutrino masses, V_{CKM} and V_{PMNS} , tree level weak decays.

Standard Model 4 – the pion/kaon story, external sources method, enhanced symmetry, the effective Lagrangian, quark masses

Standard Model 5 – rare weak decays, inputs into W,Z physics, STU and precision tests, arguments for new physics beyond the Standard Model

Supersymmetry Section

These are two lectures which give a superficial overview of the structure of supersymmetric theories and the MSSM

Supersymmetry 1 Weyl spinors, Wess-Zumino model, SUSY charges, SUSY algebra, auxiliary fields, superspace, chiral superfield, vector superfield, superpotential, F-terms and D-terms, SUSY model building

Supersymmetry 2 – properties of SUSY, the case for weak scale SUSY, construction of the MSSM, R parity, supersymmetry breaking, hidden sector, soft SUSy breaking, the Higgs sector,, EWSB, the mu problem, flavor issues.

Gravity as a Gauge Theory Section

These two lectures develop general relativity in a manner similar to our treatment of gauge theories. This emphasizes the field theoretic nature of general relativity.

Dec 8 **Gravity 1 –** Gauging Lorentz transformations, Spin transformation for fermions, local Lorentz invariance, vierbein, fermions and the spin connection, covariant derivative, forming the curvature, Einstein action and equations

Dec 10 **Gravity 2 –** review of gauge theory construction, exploring the action, higher invariants of the curvature, quantization and Feynman rules, background field renormalization, gravity as an effective field theory