Quantum Field Theory 2: the Standard Model

Syllabus

The page numbers mentioned in this short course overview refer to the handwritten lecture notes. More extended information can be found on Brightspace in the weekly content sections.

Lecture 1: page 1-7, Ex.1+2

- Summary of basic QFT concepts (scalar Lagrangians, Noether's theorem, etc.).
- QED from local U(1) gauge invariance (gauge principle, covariant derivative, field tensor, massless gauge field as force mediator, scalable Abelian gauge interactions, charge).

Lecture 2: page 7-12, Ex.3+4

- Generalising the gauge principle to describe other fundamental forces in the SM.
- Non-Abelian local SU(N) invariance for N>1 (Lie algebra, generators, matter fermions in fundamental representation, non-Abelian gauge bosons in adjoint representation, non-scalable non-Abelian interactions, triple and quartic self interactions among gauge bosons).

Lecture 3: page 12-16, Ex.5

- Experimental evidence hinting at SU(3)_c (c = colour) for describing strong interactions and SU(2)_L (L = left-handed matter-fermion chirality) for describing weak interactions.
- The weak interactions require a chiral theory and massive gauge bosons!

Lecture 4: page 16-20, Ex.6+7

- The SM gauge group is completed by adding the U(1)_Y (Y = hypercharge) gauge group.
- List of all SM matter fermions (leptons + quarks) and their gauge-group quantum numbers.
- Theoretical issue: in a chiral theory quantum corrections may invalidate the Ward identities that reflect gauge invariance (chiral anomaly), which would have disastrous consequences.

Lecture 5: page 20-23, continuation of the week 4 exercise set

- The SM is "magically" anomaly free due to the lepton-quark family structure and the lepton and quark gauge quantum numbers.
- The issue of having massive weak gauge bosons and matter fermions in the SM.
- The concept of spontaneous symmetry breaking (Higgs mechanism) to remedy this: the physical Higgs boson and the fate/role of the Goldstone bosons.

Lecture 6: page 24-27, Ex.8+9

- The SM Higgs mechanism for giving mass to the W and Z bosons and all massive fermions.
- Mixing of gauge eigenstates into mass eigenstates: SU(2)_L and U(1)_Y gauge bosons → massive W+, W-, Z bosons and massless photon, and flavour mixing in the fermion sector (e.g. CKM quark-mixing matrix).

Lecture 7: page 28-32, Ex.10

- Consequences of mixing in the quark and lepton sectors (GIM mechanism, neutrino oscillations, CP violation => at least three generations of matter fermions in the SM).

Exercises:

- **1: Setting the scene for non-Abelian SU(N) and SO(N) gauge theories**
- **2: Properties of a conjugate SU(2) doublet**
- **3: Absence of scalability of non-Abelian interactions**
- **4: Feynman rules for the SU(N) interactions (gauge interactions, TGC, QGC)**
- **5: Propagator for a massive gauge boson and the ensuing problematic UV behaviour**
- **6: Some covariant derivatives that feature in the Standard Model**
- **7: The relativistic superconductor (a Higgs toy model inspired by the Meissner effect)**
- **8: Gauge-boson masses in the Standard Model**
- **9: Neutral-current and charged-current electroweak gauge interactions for quarks**
- **10: Highlighting aspects of neutrino oscillations**