The Standard Model (L24)

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The Standard Model of particle physics is, by far, the most successful application of quantum field theory (QFT). At the time of writing, it accurately describes all experimental measurements involving strong, weak, and electromagnetic interactions. The course aims to demonstrate how this model, a QFT with gauge group $SU(3) \times SU(2) \times U(1)$ and fermion fields for the leptons and quarks, is realised in nature. It is intended to complement the more general Advanced QFT course.

We begin by describing the important role of symmetries in relativistic quantum physics and quantum field theory. We start with spacetime symmetries including representations of the Poincaré group and discrete symmetries (C,P,T). Then move to non-abelian gauge symmetries. Ideas of spontaneous symmetry breaking are applied to discuss Goldstone's theorem and the Higgs mechanism. We later apply these concepts to describe the weak interactions and their unification with electromagnetic interactions and also Quantum Chromodynamics (QCD) that describes strong interactions in terms of an $SU(3)$ gauge theory.

We put all this together to define the Standard Model in terms of its local (gauge) and global symmetries and its elementary particle content (spin-half leptons and quarks, spin-one gauge bosons and spin-zero Higgs boson).

Throughout the lectures, general consistency and fundamental properties such as the structure of gauge anomalies and asymptotic freedom will be highlighted. Also, phenomenological properties of the standard model will be introduced such as the Cabibbo-Kobayashi-Maskawa (CKM) mixing, the Glashow-Iliopoulos-Maiani (GIM) mechanism, neutrino oscillations, etc.

Both very high-energy experiments and very precise experiments are currently striving to observe effects that cannot be described by the Standard Model alone. If time permits, we comment on how the Standard Model is treated as an effective field theory to accommodate (so far hypothetical) effects beyond the Standard Model. General open questions for the standard model will be discussed at the end of the course.

General Outline

1. Introduction and History
2. Spacetime Symmetries
3. Internal Symmetries
4. Broken Symmetries
5. Weak Interactions: Electroweak unification
6. Strong Interactions: QCD
7. The Standard Model and Effective Field Theories.

Pre-requisites

It is necessary to have attended the Quantum Field Theory and the Symmetries, Fields and Particles courses, or to be familiar with the material covered in them. It would be advantageous to attend the Advanced QFT course during the same term as this course, or to study renormalisation and non-abelian gauge fixing.

Literature

1. M.D. Schwartz, *Quantum Field Theory and the Standard Model*, Cambridge University Press (2014).

2. S. Weinberg, *The Quantum Theory of Fields, Volume 1,2*, Cambridge University Press (1995).

3. C.P. Burgess and G. Moore, *The Standard Model: A Primer,* Cambridge University Press (2007).

4. C.P. Burgess *Effective Field Theories,* Cambridge University Press (2020).

5. M.E. Peskin and D.V. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley (1995).

6. F. Halzen and A.D. Martin, *Quarks and Leptons: An Introductory Course in Modern Particle Physics*, Wiley (1984).

7. I.J.R. Aitchison and A.J.G. Hey, *Gauge Theories in Particle Physics*, CRC Press (two volumes or earlier 1989 edition in one volume).

8. J.F. Donoghue, E. Golowich and B.R. Holstein, *Dynamics of the Standard Model*, Cambridge University Press (2014).

9. H. Georgi, *Weak Interactions and Modern Particle Theory*, Benjamin/Cummings (1984).

10. T-P. Cheng and L-F. Li, *Gauge Theory of Elementary Particle Physics*, Oxford University Press (1984).

11. M. Thomson, *Modern Particle Physics*, Cambridge University Press (2013).

Additional support

Four example sheets will be provided and four associated examples classes will be given. There will also be a revision class in Easter Term.