Quantum Field Theory (M24)

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Quantum Field Theory is a marriage of quantum mechanics and special relativity which provides the mathematical framework for describing the interactions of elementary particles. This first Quantum Field Theory course introduces the basic types of fields which play an important role in high energy physics: scalars, (Dirac) spinors, and gauge fields. The relativistic covariance and symmetry properties of these fields are discussed using the language of Lagrangians and Noether's theorem. The quantisation of free fields is developed using Hamiltonian methods in terms of operators which create and annihilate particles and anti-particles. The Fock space of quantum physical states and the associated realisation of particle statistics are described.

Interacting field theory is developed next using the LSZ formula for the scattering amplitude. Perturbation theory is formulated by applying the Schwinger-Dyson equation and Wick's theorem; Feynman diagrams are then introduced as an efficient way of organising the resulting calculations. Physically measurable quantities such as decay rates and cross-sections are defined. Spinors and the Dirac equation are explored in detail, along with parity and chirality. Fermionic quantisation is developed, along with Feynman rules and Feynman propagators for fermions.

We review the relativistic formulation of Maxwell's equations formulating a corresponding action principle. The significance of gauge invariance is discussed. Lorentz gauge quantisation of the electromagnetic field is accomplished by imposing the Gupta-Bleuler condition. Finally, quantum electrodynamics (QED) is developed. Interactions between photons and charged matter are introduced via the principle of minimal coupling. We discuss the calculation of tree-level scattering amplitudes in QED.

Prerequisites

You will need to be comfortable with the Lagrangian and Hamiltonian formulations of classical mechanics and with special relativity. You will also need to have taken an advanced course on quantum mechanics including Dirac's "bra/ket" notation. A basic knowledge of group theory is also very useful for this course.

Literature

1. David Tong, *Lectures on Quantum Field Theory*, **link.**
2. M. D. Schwartz, *Quantum Field Theory and the Standard Model,* Cambridge University Press, 2014.
3. M. Peskin and D. Schroeder, *An Introduction to Quantum Field Theory,* Harper Collins Publishers, 1995.
4. T. Zee, *Quantum Field Theory in a Nutshell,* Princeton University Press, 2003.
5. M. Srednicki, *Quantum Field Theory,* Cambridge University Press, 2007. **link**.
6. P. Ramond, *Field Theory: A Modern Primer,* Benjamin/Cummings Pub. Co.,1981.

Quantum field theory is an extremely vast subject. The course will mainly follow David Tong's lecture notes, and specific chapters in Schwartz's book listed above. Every book listed here has strengths and weaknesses, so it is useful to be familiar with several. For instance, Zee's book is very good for a conceptual and intuitive introduction, but lacks details on how to do computations. Srednicki's book on the other hand is very explicit on how to carry out computations, but there are few explanations and motivations. Schwartz's book gives a modern understanding of effective field theories and balances well formal aspects, explicit derivations and explanations. Ramond's book is short but has wonderful explanations which I personally find useful.

Additional support

Four examples sheets will be provided and four associated examples classes will be given. There will be a one-hour revision class in the Easter Term.