TSSTS 2020 Physics Division

TP101: Quantum Field Theory I

Guide to Course

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June 11, 2020

Introduction

This course serves as the very first stepping stone towards graduate level theoretical physics. As we saw in Quantum Mechanics, the precise predictions of many microscopic phenomena proved a great success of the theory, yet we treated microscopic particles in a *non-relativistic*, *number-conserved* manner, which is hard to describe *relativistic particles* (such as photons) and the *creation and annihilation* of particles. In this course, we will witness the marriage of Quantum Mechanics and Special Relativity, and we shall see how this leads to a new mathematical framework that enables us to talk about elementary particle interactions accurately.

This course will be based on the *Quantum Field Theory* course offered in DAMTP, University of Cambridge, and the course materials are far from original.

The whole lecture series will be roughly 24 hours, in terms of 12 two-hour lectures. The exact timing can be flexible regarding the actual circumstances.

Synopsis

Classical Field Theory

Natural units. Field dynamics: Klein-Gordon equation, Maxwell's equations. Locality. Lorentz invariance. Symmetries: Noether's theorem, energy-momentum tensor, angular momentum, internal symmetries. Hamiltonian formalism.

Free Fields

Canonical quantisation. Simple harmonic oscillator. Free scalar fields. Vacuum. Particles. Relativistic normalisation. Complex scalar fields. Heisenberg picture. Causality. Propagators. Feynman propagators. Non-relativistic fields (QM).

Interacting Fields

Interaction picture. Dyson's formula. Wick's theorem. Feynman diagrams and Feynman rules. Scattering amplitudes: Mandelstam variables, Yukawa potential, ϕ^4 theory. Connected diagrams and amputated diagrams. Fermi's golden rule. Decay rates. Cross sections. Green's functions: connected diagrams, vacuum bubbles, S-matrices.

The Dirac Equation

Spinor representation. Dirac action. Dirac equation. Chiral spinors: Weyl equation, γ^5, parity, chiral interactions. Majorana fermions. Symmetries and conserved currents. Plane wave solutions. Helicity.

Quantising the Dirac Field

Spin-statistic theorem. Fermionic quantisation (Fermi-Dirac statistics). Hole interpretation. Propagators. Feynman propagators. Yukawa theory. Feynman rules for fermions.

Quantum Electrodynamics

Maxwell's equations. Gauge symmetry. Quantisation of EM-field. Coulomb gauge. Lorenz gauge. Coupling to matter. QED. Feynman rules. Charged scalars. Scattering in QED.

Prerequisites

Previous experience with Quantum Mechanics is essential. Knowledge of Lagrangian and Hamiltonian formulations of Classical Mechanics, knowledge of Special Relativity are highly desirable.

Bibliography

1. D. Tong, *Lectures on Quantum Field Theory*
   `http://www.damtp.cam.ac.uk/user/tong/qft.html`
2. M.E. Peskin and D.V. Schroeder, *An Introduction to Quantum Field Theory*
3. M. Srednicki, *Quantum Field Theory*