Dipartimento di Fisica e Astronomia "Galileo Galilei" - Università di Padova

Outline of LM course in

Theoretical Physics - Modulo B

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The main goal of the course is to offer a basic introduction, for graduate students, to relativistic wave equations and to relativistic quantum field theory.

The modification of Schrödinger wave equation in order to describe quantum relativistic systems is introduced. Both the Klein-Gordon and Dirac wave equations are shown to lead to physical inconsistencies when interpreted as wave functions equations ("first quantization").

The need to introduce a quantum field theory approach is then considered ("second quantization"). The Langrangian and Hamiltonian description for classical fields will be shortly reviewed, focusing, in particular, to the relation between the symmetry properties of a physical system and conservation laws.

The quantization for free spin 0, spin 1/2 and spin 1 fields (in the covariant approach) is introduced, through the so called "canonical quantization" procedure. The case of interacting fields is discussed by the introduction of the scattering matrix formalism. The Feynman rules for the Quantum Electro-Dynamics (QED) theory are derived. As an example, the cross section for the $e^+ + e^- \to \mu^+ + \mu^-$ scattering process, at the lowest order, is derived.

Regular Lectures Schedule a.a. 2016/17

Mon	09.30–11.30	Aula LUF 2
Tue	11.30–13.30	Aula LUF 2
Wed	09.30–11.30	Aula LUF 2
Thu	09.30–11.30	Aula LUF 2

Contents

i) Review on non-relativistic and relativistic wave equations:
   - Schrödinger wave equation. Continuity equation and probabilistic interpretation;
   - Klein-Gordon wave equation. Continuity equation. Negative energy states and the Klein paradox;
   - Dirac wave equation. Spinorial representations. Continuity equation. Negative energy states and the Klein paradox;

ii) Review on classical field theory with a Lagrangian approach:
   - Eulero-Lagrange equation of motion for classical fields;
   - Noether theorem and conserved charge for internal and spacetime symmetries;

iii) Non relativistic quantum field theory:
   - Lagrangian density for a non relativistic scalar field;
   - Canonical quantization, commutator and anticommutation relations and Fock space;

iv) Relativistic quantum field theory for a free scalar field (spin 0):
   - Lagrangian density for Dirac spinorial fields;
   - Canonical quantization, commutator relations and Fock space;
   - Covariant commutators, Green function and propagator;

v) Field theory for free Dirac spinorial fields (spin 1/2):
   - Lagrangian density for Dirac spinorial fields;
   - Anti-commutator relations and Fock space;
   - Green function and propagator;

vi) Field theory for free vector boson fields (spin 1):
   - Lagrangian density for massive and massles vector fields;
   - Commutator relations and Fock space;
   - Massless vector bosons, gauge invariance and Gupta-Bleuler formalism;
   - Green function and propagator;

vii) Interactions in classical field theories:
   - Overview of interacting Lagrangians;
   - The case of gauge theories (SQED and QED);

viii) Interactions in quantum field theories:
   - Interaction picture and the S matrix perturbative expansion;
   - Feynman rules and lowest order Feynman diagrams;
   - Two particle final state: cross section and decay width;

ix) Calculation of QED processes at the lowest order:
   - The $e^- + e^+ \to \mu^- + \mu^+$ process;

Suggested Textbooks

You may find the material described in this course in the following textbooks on Relativistic Quantum Mechanics and Introduction to Quantum Field Theory

- R. D'Auria and M. Trigiante,
  From Special Relativity to Feynman Diagrams,
  Springler 2012;
- L. Maiani and O. Benhar,
  Meccanica Quantistica Relativistica,
  Editori Riuniti 2012;
- F. Mandl and G. Shaw,
  Quantum Field Theory (II edition),
  Wiley 2010;
- M. Maggiore,
  A modern Introduction to Quantum Field Theory,
  Oxford University Press, 2005;