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

Theoretical Physics - Modulo B

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December 28, 2016

Detailed Lecture Plan – 2016/17

[26/10] – Presentation of the course (1h) – Administrative information, brief summary of prerequisites for the course. Tentative program and goals;

– Non relativistic wave equation (1h) – Correspondence principle and non-relativistic Schrödinger equation. Continuity equation and probabilistic wave function interpretation. General solution of the free Schrödinger equation.

[27/10] – Relativistic KG wave equation (2h). Brief summary of relativistic notation and conventions. Correspondence principle and relativistic Klein-Gordon equation. Continuity equation for the KG equation and failure of the probabilistic wave function interpretation. Covariance of the KG equation.

[02/11] – Relativistic KG wave equation (2h). General solution of the (free) Klein-Gordon equation. Relativistic wave equation coupled with E.M. field. Minimal coupling and covariant derivative. Positive/negative energy solutions as particle/antiparticle coupled with E.M. field. Non-relativistic limit of the coupled KG equation and the Schrödinger (coupled) equation for a (spin 0) scalar particle.

[03/11] – Relativistic KG wave equation (1h). Derivation of the KG paradox and failure of the wave function QM approach.

– Relativistic Dirac wave equation (1h). Linear derivative relativistic equation and conditions on the Dirac γ matrices in 4D.

[09/11] – Relativistic Dirac wave equation (2h). Representations of the Dirac γ matrices. Consistency with KG equation. Relativistic principle and covariance of the Dirac wave equation. Explicit realization of the spinorial representation of the Lorentz group.

[10/11] – Relativistic Dirac wave equation (2h). The Dirac-conjugate spinor. Continuity equation for the Dirac equation. Bilinears and Lorentz transformations. General solutions of the Dirac equations. Energy and helicity projectors.

[14/11] – Relativistic Dirac wave equation (1h). The Pauli-Lubansky (pseudo)-vector. The γ_5 "chirality" matrix and connection between helicity and chirality in the ultra-relativistic limit. The spin and helicity operators.

– Relativistic Dirac wave equation coupled with E.M. (1h). Minimal coupling and covariant derivative for the Dirac equation.

[15/11] – Relativistic Dirac wave equation coupled with E.M. (1h). Non-relativistic limit of the Dirac equation and the Pauli wave equation. Prediction of the gyromagnetic factor in the relativistic and non-relativistic limit.

– System with a finite number of degrees of freedom (1h). Lagrangian vs Hamiltonian formalism: principle of Least Action and Eulero–Lagrange equations of motion. Hamilton equations as Poisson parenthesis;

[16/11] – System with an infinite (continuous) number of degrees of freedom (2 h). Lagrangian vs Hamiltonian formalism for fields: principle of Least Action and Eulero–Lagrange equations of motion. Hamilton equations as Poisson parenthesis. Definition of Functional and Functional derivative. Hamilton equations as Poisson parenthesis. Examples;

[17/11] – Symmetries and Noether theorem (2h). Internal symmetries and charge conservation; Spacetime symmetries and conservation of momentum and angular momentum;

[29/11] – (Classical) Real Scalar Field Theory (2h) – Lagrangian for real scalar fields. Eulero-Lagrange equations and spacetime conserved currents. Hamiltonian formalism and Poisson parenthesis;

[30/11] – (Classical) Complex Scalar Field Theory (1h) – Lagrangian for complex scalar fields. Eulero-Lagrange equations, spacetime and internal conserved currents. Hamiltonian formalism and Poisson parenthesis;

– Canonical Quantization for real scalar fields (1h) – General introduction. The QM example: from Poisson parenthesis to commutators. The real scalar field. Conserved operators in the momentum space. Normal ordering.

[01/12] – Canonical Quantization for real scalar fields (1h) – Definition of Fock space of particle states. Normalization of states. Spin-statistics connection;

[14/12] – Canonical Quantization for scalar fields (2h) – Covariant commutators and microcausality. Extension to the complex scalar field case. Internal global $U(1)$ symmetry and conserved charge;

[15/12] – Dirac Field Theory (1h). Lagrangian for a Dirac spinorial field. Eulero-Lagrange equations. Spacetime and internal conserved currents. Hamiltonian formalism and Poisson parenthesis.

– Canonical Quantization for the Dirac field (1h). Quantization with commutators and inconsistencies. Quantization with anticommutators;

[19/12] – Canonical Quantization for the Dirac field (1h). Fock space for fermions. Connection with the spin-statistic theorem. Covariant anticommutators and microcausality;

– Canonical Quantization for the Schrödinger field (1h). Lagrangian formulation for the Schrödinger field. Eulero-Lagrange equations. Canonical quantization with commutators and anticommutators.

[20/12] – Classical vector field theory (1h). Massive vector field Lagrangian theory. The Proca Lagrangian. Eulero-Lagrange equation for a massive vector field. Poincare group invariance and conserved currents. Hamiltonian formalism and canonical quantization (outline);

– Classical Electromagnetic field theory (1h). Maxwell equations and Electromagnetic Lagrangian. Gauge Invariance. Coulomb (radiation) gauge. Solution of the Eulero-Lagrange equation in the Coulomb gauge.

[21/12] – Classical Electromagnetic field theory (1h). The Lorentz gauge. The Gauge fixing Lagrangian. Lagrangian and Hamiltonian densities in the Feynman gauge ($\xi = 1$). General solution of the equation of motion (for $\xi = 1$);

– Covariant quantization of the E.M. field (1h). Canonical quantization in the Feynman gauge. Commutation relations for fields and creation/annihilation operators. Explicit expressions for the Hamiltonian operator. Fock space and indefinite metric. Unphysical polarizations and negative norm/energy states.

[22/12] – Covariant quantization of the E.M. field (1h). Gupta-Bleuler condition. Properties of the physical states. Covariant commutators and causality;

– Interactions in classical field theory (1h). Examples of interactions in classical field theory. Scalar self-interaction, Yukawa interaction and gauge interaction. Renormalizability condition (and power counting). Minimal coupling and gauge invariance. QED and Scalar–QED Lagrangians;

[09/01]– Quantization of an interacting theory (1h). General problems in the quantization of an interacting theory. Schrödinger, Heisemberg and Interaction pictures: definitions.

– Interaction picture and S-Matrix (1h). Evolution of operators and states in the interaction picture. The evolution operator in the Interaction picture.

[10/01] – Interaction picture and S-Matrix (1h). Perturbative expansion of the evolution matrix for weak interacting theories. The S-matrix and transition probability.

– T-products and Wick's theorem (1h). Definition of T-product and Feynman propagator for real and complex scalar fields. Wick theorem for scalar fields.

[11/01] – T-products and Wick's theorem (1h). Definition of T-product and Feynman propagator for real vector fields. Definition of T-product and Feynman propagator for Dirac spinorial fields. Generalization of Wick's theorem for generic fields. Corollary of the Wick's theorem;

– Physical interpretation of Feynman propagators (1h). Deeper look to Feynman propagators. Physical meaning and diagrammatic representation. Explicit derivation of the scalar, vector and spinor propagators. Feynman propagators in momentum space;

[12/01] – S-matrix expansion in QED (2h). Explicit derivation and interpretation of the first terms of the S-matrix expansion in coordinate space. The 0-th and 1-st order terms in the S-matrix expansion. Explicit derivation of first terms of the S-matrix expansion. Interpretation of 2-nd order terms in the expansion. Explicit discussion of diagrams in coordinate space with 0, 1, 2 and 3 propagators. $2 \to 2$ scattering processes in QED. Photon and electron self-energies;

[16/01] – Feynman diagrams in momentum space (2h). Calculation of matrix elements between states of definite momentum. Propagators and field contractions in momentum space. 0th and 1st order processes in momentum space. 2nd order diagrams in momentum space, scattering processes. Amplitude for the Compton scattering. Self-energies and loop diagrams. Summary of QED Feynman rules;

[17/01] – Massive boson decay (1h). Yukawa theory Feynman rules and massive scalar boson decay. Massive vector boson decay in fermions;

– Elementary processes in QED (1h). Explicit derivation of the $e^- + e^+ \to \mu^- + \mu^+$ un-polarized cross section;

– Example and exercises on Dirac matrices (1h).

[18/01] – Decay rates (1h). Study of $1 \to 2$ decay. Two body phase space and derivation of differential and total decay width in the Laboratory frame;

– Cross section (1h). Study of $2 \to 2$ scattering process. Two body phase space and derivation of differential and total cross section in the center of mass reference frame.