Brunel University
Queen Mary, University of London
Royal Holloway, University of London
University College London

Intercollegiate post-graduate course in High Energy Physics

Paper 1: The Standard Model and Beyond part 1

Monday, 2 February 2015

Time allowed for Examination: 3 hours

Answer four questions out of six (80 marks)

Books and notes may be consulted

The Standard Model

Question 1 (20 marks)

Describe the main measurements that have lead to the understanding of oscillation for solar and atmospheric neutrinos.

[4]

Write down the number operator of a harmonic oscillator, and explain why it has this name. **[4]**

Write down the Lagrangian of the Harmonic oscillator, and the energy (Hamiltonian) in the Lagrange formalism.

[4]

Demonstrate that Dirac's delta function can be written as a Fourier transformation of a constant function, and derive its properties. **[4]**

Starting from the Schroedinger equation, derive a conserved current. **[4]**

CONTINUED

Question 2 (20 marks)
In a collision with two particle in the final state, calculate the centre-of-mass momentum of the outgoing particles as a function of the centre-of-mass energy and the masses of the two outgoing particles **[4]**

Write down the expression for the Mandelstam variables for a scattering process with two particles in the final state, and calculate the value of their sum. **[4]**

Write down the Klein-Gordon equation, and derive the particle density and current. **[5]**

Write down how a wave function is changed by the applicaton of Green's functions between two scattering points. **[5]**

CONTINUED

Question 3 (20 marks)

Consider a scattering between two spinless different particles. How is the momentum operator modified to account for the electromagnetic interaction, and what is the value of the resulting "potential"? **[4]**

In the above case, calculate the transitional amplitude, and use it to derive the current for one of the incoming particles. **[5]**

Calculate the current in the case of planar waves, and through substitution find a suitable expression for the four-momentum A^{μ}. **[5]**

Describe what we mean by the number of final states and the initial flux of an interaction with two particles in the initial and in the final state.

[5]

CONTINUED

Question 4 (20 marks)

Write down an expression for the kinetic energy of a particle that involves the Pauli matrices, and explain why this relation is equivalent to the standard one.

[5]

Wite down Dirac's equation in terms of the α and β matrices, as well as the γ matrices, in standard and adjoint form. **[5]**

Explain the difference between the u and the v forms for the spinors of the free-particle solution of Dirac's equation.

[5]

Is the spin a conserved quantity for the Dirac Hamiltonian, and why? **[5]**

CONTINUED

Question 5 (20 marks)
Define the γ^5 matrix, and its relation with helicity. **[5]**

Write down the completeness relations, and indicate the dimension of the operatirs involved. **[4]**

Discuss the difference between a scalar and pseudoscalar, and a tensor and axial interaction, and indicate possible spinors referring to them. **[5]**

Consider an electron in an electromagnetic field, and write down the Dirac potential, and derive the electromagnetic transition current, comparing it to the spinless case. **[6]**

CONTINUED

Question 6 (20 marks)
State the main differences between the treatment of electron-muon scattering without and with spin. **[4]**

Show an example of the use of the completeness relations to simplify a squared transition amplitude. **[6]**

Show how it is possible to derive the cross-section for $e^+e^- \to \mu^+\mu^-$ starting from the electron-muon scattering. **[4]**

State the difference between real and virtual photons, in terms of the Lorentz condition, and the relations between the polarisation states. **[6]**

END OF PAPER