Institut für Theoretische Teilchenphysik

Einführung in die Flavourphysik
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Sheet 11

Problem 17: CP-violation in kaon system

Suppose that, despite all sceptics - `SETI@home` program has successfuly made contact to alien civilisation. Now, a mutual visit should be arranged but it must be clarified whether there is a risk that the delegations will approach their destination to a spectacular sky phenomenon in the form of a be violent matter-antimatter reaction. To do this, these instructions should be followed (using electromagnetic waves). Try to understand them:

a) At the mass of 0.53 of the lightest atom nucleus there exist a particle that is known at the Earth as K^0. Through the C-transformation one obtains the antiparticle:

$$C|K^0\rangle = |\overline{K^0}\rangle; \qquad P|K^0\rangle = -|K^0\rangle; \qquad P|\overline{K^0}\rangle = -|\overline{K^0}\rangle\,. \tag{1}$$

Construct the CP-eigenvectors through linear combinations of K^0 and $\overline{K^0}$.

b) One of the eigenvectors decays to two-pion states $(\pi^+\pi^-, \pi^0\pi^0)$, and another one in three-pion states $(\pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0)$ and has a longer lifetime. The pions have no relative orbital momentum.

- Why does the particle that decays to three pions have a longer lifetime.
- What CP-eigenstate is it?

We label the long-lived state as $|K_2\rangle$, and the another one as $|K_1\rangle$.
Hint: $C|\pi^0\rangle = |\pi^0\rangle$.

c) On Earth, we have measured that the long-lived state can decay to two pions as well. We denote this state as K_L^0. The experiments give

$$\frac{\Gamma(K_L^0 \to \pi^0\pi^0)}{\Gamma(K_L^0 \to \pi^0\pi^0\pi^0)} = 4 \cdot 10^{-3}\,. \tag{2}$$

Is the K_L^0 the CP-eigenstate?

d) The K_L^0 can be expressed as

$$|K_L^0\rangle = \frac{1}{\text{Norm}} \left(|K_2\rangle + \varepsilon|K_1\rangle\right) . \tag{3}$$

Then one can calculate ε^2 using the value from c) and the fact that the different magnitudes of the phase spaces in the decays to two and three pions are given directly by the ratio of lifetimes of K_S^0 und K_L^0. We have

$$\tau(K_S^0) = 0.89 \cdot 10^{-10}\, s\,, \tag{4}$$
$$\tau(K_L^0) = 5.20 \cdot 10^{-8}\, s\,. \tag{5}$$

Take ε to be real and let K_1 decay into 2, and K_2 into 3 pions. What is the value of ε^2?

e) How large are the K^0 and $\overline{K^0}$ components in K_L^0? Evaluate $\langle K^0|K_L^0\rangle$ und $\langle\overline{K^0}|K_L^0\rangle$.

f) K^0 and $\overline{K^0}$ can decay to electron, neutrino and pion. Scetch the Feynman diagrams for these processes. What are the electric charges of leptons that originate from K^0 and $\overline{K^0}$, respectively?

g) Evaluate

$$\frac{\Gamma(K_L^0 \to e^+\pi^-\nu_e) - \Gamma(K_L^0 \to e^-\pi^+\bar{\nu}_e)}{\Gamma(K_L^0 \to e^+\pi^-\nu_e) + \Gamma(K_L^0 \to e^-\pi^+\bar{\nu}_e)} \tag{6}$$

For this, consider the K^0 and $\overline{K^0}$ components in K_L. Compare the sign of the charge of the dominant leptons in the above decays with the sign of the charge of the nuclei in the ordinary matter.
Hint: The partial decay rates Γ are proportional to the squares of the matrix elements calcualted in (e).

h) Explain (how) is it possible to make sure (using only electromagnetic signals for communication with the extraterrestrial civilization) that they are made of matter and not antimatter.