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ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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СИГНАЛЬНЫЙ ЭКЗЕМПЛЯР

IS 'MUONIUM ONE' HEAVIER THAN 'MUONIUM TWO' OR VICEVERSA?

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A few years ago it was noticed[1] that muonium, the atom-like system $M \equiv (\mu^+ e^-)$, in vacuum may transform itself into antimuonium $\widetilde{M} \equiv (\mu^- e^+)$, the oscillations $M \rightleftarrows \widetilde{M}$ being analogous to the $K^0 \rightleftarrows \widetilde{K}^0$ transformations[2].

Recently in the literature there appeared a number of publications on this subject[3,4,5,6]. The aim of the present note is to emphasize that the analogy between the $M \rightleftarrows \widetilde{M}$ and the $K^0 \rightleftarrows \widetilde{K}^0$ oscillations is even deeper than it was thought to be before: there are different decay channels for the (combined parity) even systems $M_1 = \frac{(M+\widetilde{M})}{\sqrt{2}}$ and odd systems $M_2 = \frac{(M-\widetilde{M})}{\sqrt{2}}$, just as in the case of K_1^0 and K_2^0 mesons. Here M_1 and M_2 are diagonal states of muonium in vacuum.

Let us first consider the case when there is only one type of neutrino, and there is no direct (μe) interaction. It might be expected that this would be just the case, if in nature there took place the so-called Kiev symmetry[7], that is the invariance of all the weak interaction processes with respect to the interchange $\mu \rightleftarrows \Lambda$, $e \rightleftarrows n$, $\nu \rightleftarrows p$. This symmetry, and the existence of $K^0 \rightleftarrows \widetilde{K}^0$ oscillations, directly implies the existence of $M \rightleftarrows \widetilde{M}$ oscillations. Anyway, the transformation $M \rightleftarrows \widetilde{M}$ is due in such a case to the same interaction[1] which is responsible for the decay of free muon: $\mu^\pm \to e^\pm + \nu + \widetilde{\nu}$. Naturally the question arises as to how the even and odd combinations of muonium do differ. The decay channels of the (PC) odd system $M_2 = \frac{M - \widetilde{M}}{\sqrt{2}}$ will be:

$$e^+_{fast} + \nu + \widetilde{\nu} + e^-_{slow} \tag{1}$$

$$e^-_{fast} + \nu + \widetilde{\nu} + e^+_{slow} \tag{2}$$

$$\nu + \widetilde{\nu} \tag{3}$$

Here we consider muonium with spin 1, because a system with spin 0 cannot decay into a pair $(\nu \widetilde{\nu})$ of longitudinal neutrinos. The (PC) even system $M_1 = \frac{M + \widetilde{M}}{\sqrt{2}}$ may decay into the channels (1) and (2), but its decay into channel (3) is forbidden. Just as the odd K_2^0-meson, with spin 0, cannot decay into 2 pions, an even system with spin 1 cannot decay into $\nu + \widetilde{\nu}$. According to Lehman's theorem[8], it can be stated that the mass of M_2, which has an additional decay channel, is greater than the mass of M_1. As is well known, the question[9] as to whether the K_1^0-meson is heavier than the K_2^0-meson or viceversa cannot be answered on theoretical ground on account of the difficulties arising from the strong interactions of these particles.

Contrary to the case of K_1^0 and K_2^0, the difference in the decay properties of M_1 and M_2 is of course extremely small. The physical reason of this lies in the large dimensions of our atom-like system:

although the decay systems, strictly speaking, are M_1 and M_2, in point of fact it is the 'independent' muon inside the atom-like system which does decay in most cases. As a matter of principle, however, a difference in the decay modes of M_1 and M_2 does exist and it seemed to us worth while to point out this circumstance if only from a pedagogical point of view.

The above arguments on the different decay channels of M_1 and M_2 keep their validity also when there is a direct $(\mu e)(\mu e)$ interaction/1/, but the difference Δ in the M_1 and M_2 masses will be then determined/10/ by this interaction, and we are not able to say anything on the sign of Δ.

Let us assume now that in nature there are two types of neutrino ν_e and ν_μ /11/. If e and ν_e, on one hand, μ and ν_μ, on the other hand, are characterized by different additive quantum numbers (charges), the transitions $M \rightleftarrows \tilde{M}$ are strictly forbidden, and the combinations M_1 and M_2 have no physical meaning.

Let us discuss now the possibility suggested recently/12/, /13/, that there might exist multiplicative quantum numbers. According to this point of view, the muon decay is

$$\mu^+ \rightarrow \left\{ \begin{array}{l} e^+ + \nu_e + \tilde{\nu}_\mu \\ e^+ + \tilde{\nu}_e + \nu_\mu \end{array} \right. ,$$

and the transitions $M \rightleftarrows \tilde{M}$ are due to a direct $(\mu e)(\mu e)$ interaction. In such a case there is no difference in the decay modes of M_1 and M_2. For M_1 as well as for M_2 the following channels are possible:

$$\begin{array}{c} e^+_{fast} + \nu_e + \tilde{\nu}_\mu + e^-_{slow} \\ e^-_{fast} + \nu_e + \tilde{\nu}_\mu + e^+_{slow} \\ e^+_{fast} + \tilde{\nu}_e + \nu_\mu + e^-_{slow} \\ e^-_{fast} + \tilde{\nu}_e + \nu_\mu + e^+_{slow} \\ \nu_e + \tilde{\nu}_\mu \\ \tilde{\nu}_e + \nu_\mu \end{array}$$

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