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TRULY NEUTRAL MICROOBJECTS AND OSCILLATIONS IN PARTICLE PHYSICS

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At present oscillations between different states are widely discussed in particle physics. The oscillating microobjects are not described by stationary states and are "mixtures" of objects with definite mass. One of such phenomena (oscillations $K^\circ \rightleftarrows \bar{K}^\circ$) was first discussed by Gell-Mann and Pais[1] and later investigated in a number of experiments. As it seems, other types of oscillations which were considered so far have not yet been observed (at least there is no certainty about their having been observed). The oscillations at issue are muonium-antimuonium[2], neutrino oscillations[3], $D^\circ \leftrightarrow \bar{D}^\circ$[4], $n \leftrightarrow \bar{n}$[5]...

If PC-invariance holds, the stationary states describe truly neutral particles*. Further we shall assume that PC-invariance does takes place, although this hypothesis looks unlikely in a number of cases. The point is that (small) PC-violations are irrelevant from the point of view of our discussion, which is didactic in nature.

Of course the masses of microobjects discribed by stationary states are different. However, there are also other physical differences. It is just the purpose of the present note to clear up the matter about such differences. In the case of neutral kaons the question at issue is entirely clear. It is well known[7], that $K_L \cong K_2$ is heavier than $K_S \cong K_1$. The decay probabilities in various channels for K_1 and K_2 and thus their mean lives are quite different [1].

In the case of neutrino oscillations the particles with definite Majorana masses[3] $\nu_1, \nu_2, ...$ also differ in their physical behaviour. For example it is proper to say[8], that "relict" neutrinos are $\nu_1, \nu_2, ...$ (and not the "weak interaction" neutrinos $\nu_e, \nu_\mu, \nu_\tau, ...$). By the way, neutrinos $\nu_1, \nu_2, ...$ have different probabilities of radiative decay $\nu_i \to \nu_k + \gamma$[9], the lightest neutrino being the only stable one.

At the present, after the original investigation of Kuzmin[5], and in connecting with Great Unification Theories,

* The case of Dirac neutrinos[6] is not being considered in the present note.

there are widely discussed[10] and planned experiments aimed to observe neutron-antineutron ($n \rightleftarrows \bar{n}$) oscillations[11]. When these are present, in vacuum and in absence of external fields, the particles with definite masses (we shall call them Majorana neutrons) are described by the states

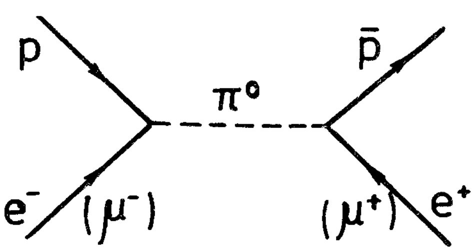
$$n_1 \cong \frac{n+\bar{n}}{\sqrt{2}}, \quad n_2 \cong \frac{n-\bar{n}}{\sqrt{2}}. \qquad (1)$$

We must not forget that we allow only a small PC-violation. If such violation does take place n_1 and n_2 will be "quasi-majorana" objects, the average baryon number of which is not exactly zero (the sign ~ in Eq. (1) is just referring to such a case).

Thus how it is possible to distinguish n_1 and n_2 from each other? One can say again that it is the values of their masses which does distinguish them. However such an answer is obviously right but only partial and thus does not satisfy us. There must be additional physical differences (let us say in decay probabilities of various channels). The main decay channels of n_1 and n_2 are β-decays, which under PC-invariance are identical and charge-symmetric.

Let us assume that, in addition to the interaction originating $n \rightleftarrows \bar{n}$ oscillations, there is also an interaction[12] responsible for the nucleon decay ($\Delta B = 1$, $\Delta(B-L)=0$, where B and L are the baryon and lepton numbers).

Then there will be marked differences in some (very unprobable) n_1 and n_2 decays which are due to such interaction. In order to illustrate this point let us consider the decays of Majorana neutrons in which one neutral pion and one neutrino are emitted. Since n_1, n_2 and the π^0-meson are particles of definite combined PC parity, the emitted neutrino must be a Majorana neutrino ν_M. This decay is forbidden (permitted) for the PC-even n_1 but permitted (forbidden) for the PC-odd n_2, depending upon the PC-parity of the emitted Majorana neutrino. In other words either the decay $n_1 \to \pi^0 + \nu_M$ or the decay $n_2 \to \pi^0 + \nu_M$ are permitted but not both.



Let us discuss now a similar question, relating to hydrogen-antihydrogen ($e^-p \to e^+\bar{p}$) oscillations. We shall consider first the "popular" decay of the proton with the emission of one positron and one neutral pion[12]: $p \to e^+ + \pi^0$. It is clear that in second order oscillations $H \to \bar{H}$ must arise (see the Figure).

Here the neutral microobjects $H_1 = \frac{H+\bar{H}}{\sqrt{2}}$ and $H_2 = \frac{H-\bar{H}}{\sqrt{2}}$ are the PC-even and PC-odd systems, correspondingly.

Of course, H_1 and H_2 have different masses. In addition H_1 and H_2 can be distinguished by the fact that, for example, the decay $H_1 \to \pi^0 + \pi^0 (\pi^+ + \pi^-)$ is permitted but the decay $H_2 \to \pi^0 + \pi^0 (\pi^+ + \pi^-)$ is forbidden. A similar situation takes place in the case of oscillations $(p\mu^-) \rightleftarrows (\bar{p}\mu^+)$ (see the Figure) in the hydrogen μ-atom.

If moderately small PC-violations do take place, the differences indicated above in the H_1 and H_2 decay channels are not so striking. Such violations have also the effect that the amplitude of hydrogen-antihydrogen oscillations would not be maximum. If the PC-violation is very strong, our argument is no more valid since the microobjects at issue are not even "approximately neutral": they "have no antiparticles".

The following words belong to L.Okun[13]: "Possibly it would be of interest to look for oscillations of atoms into anti-atoms (for example $e^-p \rightleftarrows e^+p^-$), although at present one does not see any theoretical basis for such oscillations and, moreover, even if such oscillations were existing, they would be very slow because of the large atom dimensions". Here L.Okun has in mind a direct (first order) interaction, the existence of which would have very important consequences. In this case also our argument about different decay channels of "diagonal" microobjects H_1 and H_2 is valid.

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Истинно нейтральные микрообъекты и осцилляции в физике частиц

Обсуждается вопрос о том, как можно отличить микрообъекты с определенными массами в случаях разного типа осцилляций в физике частиц.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Truly Neutral Microobjects and Oscillations in Particle Physics

In connection with various possible types of oscillations in particle physics, the question is discussed how to distinguish in principle the microobjects represented by mass eigenstates.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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