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B. Pontecorvo

"INVERSE β-PROCESSES AND NON-CONSERVATION OF LEPTON CHARGE"

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Non long ago the question was raised[1/] as to whether there exist neutral particle mixtures, other than K^0 mesons[2/], that is particles for which the transition particle→antiparticle is not strictly forbidden, although the particle at issue is an entity distinct from the corresponding antiparticle. There was noted that neutrino may be such a particle mixture and consequently that there is a possibility of real transitions neutrino→antineutrino in vacuum, provided that the lepton (neutrino) charge[3/] is not conserved. In the present note we consider in more detail this possibility, which became of some interest in connection with new investigations of inverse β-processes.

Recently there come to our attention a paper by Davis[4/], who investigated the production of A^{37} from Cl^{37} under bombardment of neutral leptons emitted by a powerful reactor. Davis' result - a measurable probability of the investigated process - <u>if it is confirmed</u>, definitely indicates that neutrino charge is not strictly conserved. Below it is assumed that:

a) the neutrino (ν) and antineutrino ($\tilde{\nu}$) emitted in the processes

$$p \longrightarrow n + \beta^+ + \nu$$
$$n \longrightarrow p + \beta^- + \tilde{\nu} \qquad (1)$$

are not identical particles.

b) the neutrino charge is not strictly conserved, from which is follow that processes

$$p \longrightarrow n + \beta^+ + \tilde{\nu}$$
$$n \longrightarrow p + \beta^- + \nu \qquad (2)$$

are possible, although by definition they are less probable than processes (1).

The physical reason of the distinguishability of neutrino and antineutrino is not discussed here; it could be connected with the non-strict conservation law for some kind of quantum number (neutrino charge?) in analogy with K^0 and $\bar{K}^0$ mesons, the distinction between which is connected with the non strict conservation law for strangeness[2].

It follows from a) and b) that neutrinos in vacuum can transform themselves into antineutrino and vice versa. This means that neutrino and antineutrino are particle mixtures i.e. symmetrical and antisymmetrical combination of two truly neutral Maiorana particles ν_1, and ν_2 having different combined parity[5].

The possibility discussed above does not simplify β decay theory and, moreover, is not likely to be true. Nevertheless we have mentioned it because it has some consequences which in principle can be tested experimentally. So, for example, a beam of neutral leptons from a reactor which at first consist mainly of antineutrinos will change its composition and at a certain destance R from the reactor will be composed of neutrino and antineutrino in equal quantities. Provided $R \lesssim$ I meter (the plausibility of this is discussed below) experiments with neutrinos reminding the experiments with K^0 mesons planned by Pais and Piccioni[2] become possible. Thus, if $R \lesssim 1$ m the cross section for the production of a neutron and a positron in hydrogen by neutral leptons from a reactor (experiment of Reines and Cowan[6]) must be smaller than that expected on the bases of simple thermodynamical considerations. This is due to the fact that the neutral lepton beam which at the source is capable of inducing the reaction with a definite probability, changes its composition on the way from the reactor to the detector. On the other hand it is difficult to anticipate the effect of real antineutrino→neutrino transitions in the Davis' experiment[4/], since in this case one deals with a non strictly inverse β process, and there may be such unknown factors as the polarisation and the energy dependence of the polarisation of neutral leptons from the reactor as well as from the decay $A^{37} \longrightarrow Ce^{37}$. Consequently it is not possible to conclude a priori - as it would be in the case of parity conservation - that the antineutrino beam, which at first is essentially uncapable of inducing the reaction in question, transforms itself into a beam in which a definite fraction of particles can induce such reaction. However it cannot be excluded that the apparent contradiction between the small probability of double β decay processes[7/] and the relatively high probability of A^{37} production in Davis' experiment[4/] is partly connected with a change in the composition of the neutral lepton beam on the way from the reactor to the detector in the last experiment.

The upper limit of R which can give observable effects in the experiment of Cowan and Reines[6/] is of the order of a meter, which corresponds to a time for the transformation neutrino→antineutrino $T \lesssim 10^{-8}$ sec. If one takes into account that the neutrino energy - as pointed out by I. Pomeranchuk - is always larger by several orders of magnitude than $m_\nu c^2$ (m_ν is the neutrino rest mass) and that, consequently, in the laboratory system there is a considerable relativistic increase of the transformation time, then the question arises as to whether the dondition $T \lesssim 10^{-8}$ sec is plansible at all even if assumptions a) and b) are true. The time T is connected with the mass difference Δm of particles ν_1 and ν_2. Δm is proportional to the first power of the matrix element H of the transition $\nu \rightleftharpoons \tilde{\nu}$, about which, unfortunately, it is impossible to say anything definite, unless a more concrete assumption on β decay processes is done: for example, Preston[8], assumed that the scalar term in the interaction is responsible for neutrino emission and the tensor term for antineutrino emission, the corresponding coupling constants being different but of comparable values. In such a case the $\nu \longrightarrow \tilde{\nu}$ transformation is due to two virtual transitions, everyone of which is characterized by a coupling constant of the same order as the constant G of all weak interaction ($G \sim 10^{-7} - 10^{-6}$ in ~~m~~units $\hbar = c = \mu = 1$, where μ is the pion mass). Consequently H will be proportional to G^2, and Δm turn out to be about 10^{-11} me. The time T is[9] about $10^{-10} \times \frac{\text{neutrino energy}}{m_\nu c^2}$ sec, which is considerably greater than 10^{-8} sec.

Nevertheless there might exist a direct interaction (of the first order in G) responsible for the neutrino $\rightarrow$ antineutrino transformation

$$\nu \longrightarrow (\tilde{\nu} + N + \tilde{N}) \longrightarrow \tilde{\nu}$$

In this case Δm is proportional to the first power of the coupling constant[9] and T turns out to be about $10^{-16} \times \frac{\text{neutrino Energy}}{m_\nu C^2}$ sec. For neutrino eneries 1MeV and taking $m_\nu = 100\,\text{ev}$ (experiments[10] indicate that the neutrino mass is less than 500 ev), we get $T \sim 10^{-12}$ sec.

In conclusion it is interesting to underline that, independently of the plausibility of the concrete effects which were discussed above, non-conservation of neutrino charge under the condition that neutrino and antineutrino are distinguishable entities (or, which is the same, the existence of two Maiorana neutrinos with different combined parities) inevitably leads to effects of the Gell-Mann-Pais-Piccioni type[2]. Under the above assumptions effects of transformation of neutrino into antineutrino and vice versa may be unobservable in the laboratory because of large values of R, but will certainly occur, at least on an astronomic scale.

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