INVERSE BETA PROCESSES AND NONCONSERVATION OF LEPTON CHARGE

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RECENTLY the question was discussed[1] whether there exist other "mixed" neutral particles beside the K^0 mesons,[2] i.e., particles that differ from the corresponding antiparticles, with the transitions between particle and antiparticle states not being strictly forbidden. It was noted that the neutrino might be such a mixed particle, and consequently there exists the possibility of real neutrino ⇄ antineutrino transitions in vacuum, provided that lepton (neutrino) charge[3] is not conserved. In the present note we make a more detailed study of this possibility, in which interest has been renewed owing to recent experiments dealing with inverse beta processes.

Lately there appeared the work of Davis,[4] who used a powerful reactor to study the process of A^{37} formation from Cl^{37} under the influence of neutral leptons. The result of the Davis experiment — a nonzero probability for the process under study — if confirmed, definitely shows that the (strict) law of neutrino charge conservation is not valid. Below we assume that:

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

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

are not identical particles;

(b) the strict law of neutrino charge conservation is not valid and consequently processes of the type

$$p \rightarrow n + \beta^+ + \tilde{\nu}, \quad n \rightarrow p + \beta^- + \nu. \qquad (2)$$

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

We do not go here into the physical reason for the distinction between neutrino and antineutrino; it might be connected with an approximate conservation law of some quantum number of the type of neutrino charge (analogously to the case of K^0 and $\tilde{K}^0$ mesons, the difference between which is connected with the approximate law of conservation of strangeness).

It follows from the above assumptions that in vacuum a neutrino can be transformed into an antineutrino and vice versa. This means that the neutrino and antineutrino are "mixed" particles, i.e., a symmetric and antisymmetric combination of two truly neutral Majorana particles ν_1 and ν_2 of different combined parity.[5]

The possibility outlined above does not simplify the theory of β decay and, in addition, it probably does not correspond to actuality. Nevertheless, we are setting it forth since it leads to consequences which, in principle, can be tested experimentally. Thus, for example, a stream of neutral leptons consisting mainly of antineutrinos when emitted from a nuclear reactor, will consist at some distance R from the reactor of half neutrinos and half antineutrinos. Under the condition that $R \lesssim 1$ m (the probability for this is discussed below) neutrino experiments, reminiscent of the Pais-Piccioni experiments with K^0 mesons, become possible. Thus, in the experiment of Cowan and Reines,[6] if $R \lesssim 1$ m, when the neutral particles from the reactor are captured by hydrogen, the cross section for formation of neutrons and positrons should be smaller than the cross section expected on simple thermodynamic grounds. This is due to the fact that the stream of neutral leptons, which at creation has a known probability for initiating the reaction, has its composition changed on the way from the reactor to the detector. It would be most interesting to perform the experiment of Ref. 6 at different distances from the reactor. On the other hand, it is difficult to predict the effect of real antineutrino → neutrino transitions on the Davis experiment,[4] for we do not deal here with a strictly inverse β process, and various unknown factors may be important, such as the polarization and energy dependence of the polarization of the neutral leptons from the reactor and from $A^{37} \rightarrow Cl^{37}$ transitions. Therefore, one cannot state a priori, as one could if parity were conserved, that the antineutrino stream, which at creation is essentially unable to initiate the reaction under discussion, is transformed into a stream with a well-defined fraction capable of initiating the reaction. However, one cannot exclude the possibility that the apparent contradiction — the small probability of double β-decay[7] and the relatively large probability of observing A^{37} (Ref. 4) — is partially due to the possibility that in the experiment of Ref. 4, the stream of neutral particles changes its composition on the way from reactor to detector.

The upper limit of R, which can give rise to the mentioned effect in the experiment of Cowan and Reines, is on the order of 1 m, which corresponds to a lifetime $T \lesssim 10^{-8}$ sec for the $\nu \rightleftarrows \tilde{\nu}$ transformation. If one takes into consideration, as pointed out by I. Ia. Pomeranchuk, that the neutrino energy is always at least several orders of magnitude larger than $m_\nu c^2$ (m_ν = neutrino rest mass), and therefore one has in the laboratory system a considerable relativistic dilation of the transformation time, one is faced with the question whether the condition $T \lesssim 10^{-8}$ sec is not completely improbable even under assumptions (a) and (b). The time T is related to the mass difference Δm between the particles ν_1 and ν_2. Δm is proportional to the first power of the matrix element H for the transition $\nu \rightleftarrows \tilde{\nu}$, about which unfortunately nothing definite can be said without some more detailed assumptions regarding the β-process — such as, for example, the Preston scheme,[8] according to which the scalar covariant in the interaction is responsible for the emission of neutrinos, the tensor for the antineutrinos, with comparable although different coupling constants. In that case the transformation $\nu \to \tilde{\nu}$ is caused by two successive virtual transitions, each of which is characterized by a coupling constant on the order of the constant G of weak interactions ($G \sim 10^{-7} - 10^{-6}$ in units $\hbar = c = \mu = 1$, where $\mu = \pi$-meson mass); hence H will be proportional to G^2 and $\Delta m \sim 10^{-11} m_e$. The time[9] T turns out to be $\sim 10^{-10} \times$ (neutrino energy)/($m_\nu c^2$) sec, which is considerably longer than 10^{-8} sec.

However, one cannot exclude a direct (first order in G) interaction responsible for the neutrino-antineutrino transformation

$$\nu \to (\tilde{\nu} + N + \tilde{N}) \to \tilde{\nu}.$$

In this case Δm is proportional to the first power of the coupling constant,[9] and $T \sim 10^{-16} \times$ (neutrino energy)/($m_\nu c^2$) sec. For a neutrino of 1 Mev energy with $m_\nu c^2 = 100$ ev (experiments[10] show that $m_\nu c^2 \lesssim 500$ ev), one gets $T \sim 10^{-12}$ sec.

In conclusion we wish to emphasize that, independently of the probability of the concrete effects discussed above and of the form of the theory, nonconservation of neutrino charge with distinct neutrino and antineutrino (or, what is the same, the existence of two Majorana neutrinos with different combined parity) inescapably leads to effects of the Gell-Mann — Pais — Piccioni[2] type. The effects due to neutrino-antineutrino transformations may not be observable in the laboratory, owing to the large R but they will take place on an astronomical scale.

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ANGULAR ANISOTROPY IN THE EMISSION OF FRAGMENTS UPON FISSION OF Pu^{239} *BY 14-MEV NEUTRONS*

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IT was found in previous work[1-5] that the angular distribution of fission fragments, where the fission is induced by fast particles, is anisotropic, and that the extent of the anisotropy (the ratio of the probability of emission of the fragments in directions parallel and perpendicular to the incident particle beam) depends on the nature of the target nucleus.

From considerations developed by A. Bohr,[6] one would expect a large anisotropy in the fast-