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THE EXISTENCE OF TWO NEUTRINOS AND THE ANALYSIS OF THE LEPTONIC
CURRENTS STRUCTURE IN STRANGENESS NON-CONSERVING PROCESSES

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Recent experiments ¹⁾ have shown that the weak interactions of strange particles have a more complicated structure than hitherto expected. No theory, indeed, accounts for their newly disclosed properties except at a very phenomenological level.

Under these conditions it seems particularly necessary to keep an open mind also as regards the structure of the leptonic currents involved. The two-neutrinos experiment ²⁾ has provided information on the leptonic current associated with the strangeness conserving leptonic interaction, and has shown it to be

$$(\bar{e} \gamma) + (\bar{\mu} \gamma')$$
(1)

where, inside the parenthesis, the proper combination of γ matrices has to be understood. It would, however, obviously be arbitrary to assume without check that this same combination of leptons also governs the strangeness non-conserving weak interactions. These, indeed, involve at least three different strangeness non-conserving currents G_i ($i = 1, 2, 3$) [for instance G_1 may stand for the $\Delta I = \frac{1}{2}$ current, G_2 and G_3 for the two $\Delta I = \frac{3}{2}$ currents] and each of these can a priori be coupled with a leptonic current of its own, having the general form

$$(\bar{e} \gamma_i) + (\bar{\mu} \gamma'_i)$$
(2)

where γ_i and γ'_i are six arbitrary linear combinations of γ and γ' . Particularly attractive special cases of such structures have already been suggested by Bludman ³⁾ and by Feinberg, Gürsey and Pais ⁴⁾. Any special assumptions of such kinds are bound, however, in the present stage of our knowledge, to be purely speculative and to look somewhat arbitrary.

Clearly, if the experimental determination of the numerical coefficients in the linear combinations ν_i, ν'_i can be done without making any a priori assumption on their relative values, this will be by far the most reliable procedure. It is the purpose of this note to point out that, although the complete determination of these coefficients requires difficult high energy neutrinos experiments, a complete analysis of the K_{e3}^0 decays presently under study can nevertheless give a partial answer to the problem.

I) Analysis of K_{e3}^0 decays

This is a straightforward generalization of the conventional analysis ⁵⁾ and we therefore give only the results. It is convenient to consider the two amplitudes a, a' for $K^0 \rightarrow \pi^+ e^- + \bar{\nu}$ and $K^0 \rightarrow \pi^+ e^- + \nu'$ as the two components of a vector $\vec{A}(a, a')$ in a two-dimensional space P ; similarly for $\vec{B}(b, b')$ ($K^0 \rightarrow \pi^- e^+ + \nu$; $K^0 \rightarrow \pi^- e^+ + \nu'$). The partial decay rates for K_1^0 and K_2^0 into $\pi^\pm e^\mp + \text{neutrino}$ are then

$$\Gamma_1 = |\vec{A} + \vec{B}|^2 ; \quad \Gamma_2 = |\vec{A} - \vec{B}|^2 .$$

It is therefore convenient to write

$$\vec{V}_1 = \vec{A} + \vec{B} ; \quad \vec{V}_2 = \vec{A} - \vec{B} ; \quad \Gamma_1 = |\vec{V}_1|^2 ; \quad \Gamma_2 = |\vec{V}_2|^2 .$$

Starting with a pure K^0 beam, the ratio of $e^+ \pi^-$ to $e^- \pi^+$ decays as a function of time, is, using standard notations ¹⁾ :

$$R(t) = \frac{N^+(t)}{N^-(t)} = \frac{\Gamma_1 e^{-\lambda_1 t} + \Gamma_2 e^{-\lambda_2 t} + 2\Delta e^{-\frac{\lambda_1 + \lambda_2}{2} t} \cos(\delta\omega \cdot t)}{\Gamma_1 e^{-\lambda_1 t} + \Gamma_2 e^{-\lambda_2 t} - 2\Delta e^{-\frac{\lambda_1 + \lambda_2}{2} t} \cos(\delta\omega \cdot t)}$$

with

$$\Delta = \vec{V}_1 \cdot \vec{V}_2 \equiv \sqrt{\Gamma_1 \Gamma_2} \cos \theta ; \quad \theta = (\vec{V}_1, \vec{V}_2) .$$

It is worthwhile to stress the following two points :

- (a) the experimental data now depend on three arbitrary parameters, Γ_1 , Γ_2 and Δ , instead of just two, as would be the case if association (1) were universal ($\theta = 0$ or π). Measuring Γ_1, Γ_2 and just the sign of $N^+ - N^-$ is therefore no longer sufficient to give a complete picture of the phenomenon. Quantitative measurements on R are now necessary.
- (b) the present experiment can obviously determine nothing more than the three quantities $\Gamma_1, \Gamma_2, \theta$, i.e., the shape of the triangle made by $\vec{V}_1$ and $\vec{V}_2$. It cannot determine the over-all orientation of the triangle in the plane. This means that we have, really, to introduce one more vector, $\vec{V}_\beta$, pertaining to the lepton current associated with beta decay, and which, according to formula (1), lies by convention along the first axis in the plane P. The angle between $\vec{V}_\beta$ and, say, $\vec{V}_1$ is not accessible to the present experiment.

II) Isotopic spin analysis

The above situation is still fairly satisfactory in that all the intrinsic properties of the phenomenon (shape of the triangle) are in principle determined from the experiment. If now, however, we introduce K_{e3}^+ decay into the picture, we immediately see that this is no more the case. Here again the association of the leptons is represented by a vector $\vec{V}_+$, whose length is given by Γ_+ , the partial decay rate for K_{e3}^+ : but obviously the relative orientation of $\vec{V}_+$ with respect to $\vec{V}_1$ and $\vec{V}_2$ is not given by experiments

on K decays. As regards the conventional analysis in $(\Delta I, \Delta I_3) = (\frac{1}{2}, \frac{1}{2})$, $(\frac{3}{2}, \frac{1}{2})$, $(\frac{3}{2}, \frac{3}{2})$, it has to be modified (in an obvious way) by replacing the amplitudes in the three isotopic spin channels by two component vectors in P.

An interesting question is : could now the vector currents be pure $\Delta I = \frac{3}{2}$? This hypothesis can be shown to imply

$$\frac{2\sqrt{\Gamma_+}}{\Gamma_2} = 1 + \frac{\Gamma_1}{\Gamma_2} - 2\sqrt{\frac{\Gamma_1}{\Gamma_2}} \cos\theta .$$

It seems to be ruled out by experiment.

III) High energy neutrinos experiments

Determinations of, e.g., $(\vec{V}_3, \vec{V}_1)$ or $(\vec{V}_3, \vec{V}_+)$ require high energy neutrino experiments, such as, for instance, allowing a ν' (from π decay) incident on a nucleon to give a hyperon plus an electron. The list of all processes of a similar kind that should in principle be measured in order to know all the phases is unfortunately quite long. Because of the fact that the leptonic partial decay rates of the hyperons are at least a factor 10 smaller than predicted by universality, the present data ²⁾ do not yet give any significant information on such processes.

The only piece of information that these data give so far on such problems is that $\alpha \lesssim 26^\circ$, where $\sin \alpha$ is the ν admixture in the muonic current coupled to the axial vector $\Delta I = \frac{1}{2}$ current (one should point out in this connection that vector and axial vector strangeness non-conserving currents with the same $\Delta I, \Delta I_3$ can be coupled to leptonic currents having different structures in the sense of the present paper). This comes from the K produced neutrinos.

Summarizing, one sees that - generally speaking - the determination of such relative phases will require elaborate neutrino experiments. One of them, however, namely Θ , is accessible through a different method, which is based simply on taking full advantage of the information contained, in principle, in the K_{e3}^0 experiments that are presently being done. If Θ turns out to be zero or π , then this must also hold for other phases and the incentive to perform the neutrino experiments of the type alluded to will be very great.

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R E F E R E N C E S

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