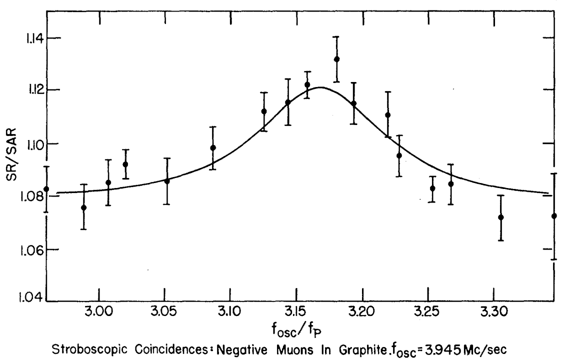

FIG. 3. Stroboscopic coincidences obtained with μ^- in a field of about 300 gauss. Target: graphite. SR/SAR: see text. f_{osc}/f_P = oscillator frequency/proton resonance frequency (f_{osc} = 3.845 Mc/sec).

only published[13] value of f_{μ^-} has an uncertainty of ± 5%.

We are greatly indebted to Professor M. Schein for the loan of a permanent magnet, and to Mr. M. Pyka for able assistance in data taking.

A full account of the novel technique, including many variants not mentioned here, is being prepared.

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REST MASS OF THE NEUTRINO*

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Although the rest mass of the neutrino has been measured to be small by experimentalists[1,2] and assumed to be zero by most theoreticians,[3] it seems worthwhile to examine the old problem of the neutrino mass in the light of recent advances in β-decay physics. Firstly, we investigate the role played by the vanishing mass of the neutrino in the current theories of parity-nonconserving weak interactions. Secondly, we point out modifications necessary in estimating the neutrino mass from the shape of the β spectrum when parity is not conserved. In particular, we show that it is impossible to determine the neutrino mass from the energy difference between the H^3-He^3 mass difference and the extrapolated end-point energy in the β decay of H^3, and that the recent results of Friedman and Smith[4] based on such a subtraction procedure throw no light on the neutrino mass.

As is well known, the two-component theory of the neutrino as formulated by Salam,[5] by Landau,[6] and by Lee and Yang[7] rests upon the hypothesis that the neutrino mass is strictly zero. Meanwhile, Case[8] has shown that the physical consequences of the two-component theory are indistinguishable from those of a special case of the Majorana theory with a parity-nonconserving Hamiltonian, and has pointed out an interesting relation between the rate of double β decay, the degree of parity nonconservation, and the mass of the neutrino.

Recently, what we may call the universal VA theory has been proposed by several authors.[9-11] The fundamental postulates of this theory (in various equivalent formulations) treat the neutrino and the electron (as well as other fermions) on an equal footing irrespective of the mass of the fermion in question. Although the neutrino mass can vanish, it does not have to vanish, and the fact that $1+\gamma_5$ appears in front of the neutrino field has nothing to do with the vanishing mass of the neutrino.

From "elegance" considerations, a finite mass of the neutrino may seem somewhat distasteful. However, as long as we have no answers to problems concerning the origin of lepton masses — e.g., the reason why the muon is 207 times heavier than the electron—it may be worth keeping an open mind on the question of the neutrino mass.

The spectrum of a parity-nonconserving β decay under the assumption that the neutrino mass need not necessarily vanish is given by[12]

$$P(E_e)dE_e \sim \rho(E_e)\left(1 + \frac{\lambda m_e m_\nu}{E_e(E_e^{max} - E_e + m_\nu)}\right)dE_e , \tag{1}$$

where

$$\lambda = \frac{|M_F|^2(-|C_V|^2 + |C_V'|^2) + |M_{GT}|^2(-|C_A|^2 + |C_A'|^2)}{|M_F|^2(|C_V|^2 + |C_V'|^2) + |M_{GT}|^2(|C_A|^2 + |C_A'|^2)} , \tag{2}$$

$$\rho(E_e) = p_e E_e (E_e^{max.} - E_e + m_\nu)\,[(E_e^{max.} - E_e + m_\nu)^2 - m_\nu^2]^{\frac{1}{2}} . \tag{3}$$

The definitions of C_i and C_i' coincide with those of Lee and Yang.[13]

In the "old" theory,[14,15] $C_i \neq 0$ and $C_i' = 0$ meant an "even" coupling[16] (the parity of the neutral particle emitted in β^+ decay being the same as that of the e^- with the usual "convention" that the proton and the neutron have the same intrinsic parity[17]), and $C_i = 0$ and $C_i' \neq 0$ meant an "odd" coupling[18] (the parity of the neutral particle in β^+ decay being opposite to the e^- parity). Parity nonconservation implies that both "even" and "odd" couplings contribute, and in particular $\lambda = 0$ if $C_i = \pm C_i'$.

The structure of the λ term can be easily understood by considering the transformation

$$\psi_\nu \rightarrow \gamma_5 \psi_\nu , \quad m_\nu \rightarrow - m_\nu , \tag{4}$$

under which the free-field Lagrangian for the neutrino is invariant. In the "old" theory, the transformation (4) amounts to changing the intrinsic parity of the neutrino; hence consequences of an "odd" coupling can be obtained from those of the corresponding "even" coupling just by reversing the sign of m_ν (but leaving $E_\nu = E_e^{max.} - E_e + m_\nu$ unchanged).[19] The parity-nonconserving universal VA theory (which leads to $C_V = C_V' \cong - C_A = - C_A'$) is invariant under (4).[11] Hence a term odd in m_ν cannot possibly appear, which explains why $\lambda = 0$.

Recent "parity" experiments indicate $C_i = + C_i'$ for V and A (and $C_i = - C_i'$ for S and T if they contribute at all) to an accuracy of 10%. Then for a finite neutrino mass the deviation from the straight-line Kurie plot arises solely from the statistical factor $\rho(E_e)$. Then from (3), we have

$$E_e^{max.} = E_e^{extr.} - m_\nu , \tag{5}$$

where $E_e^{extr.}$ stands for the extrapolated β end point in the standard Kurie plot, as previously noted by Kofoed-Hansen.[20]

Recently Friedman and Smith[4] have obtained directly a value for the H^3-He^3 mass difference. If we knew the true end-point energy $E_e^{max.}$ for the H^3 decay, we could obtain the neutrino mass from the relation

$$M_{H^3} - M_{He^3} = E_e^{max.} + m_\nu . \tag{6}$$

However, what we know accurately, and what is usually tabulated[21] as the "best" Q value, is the extrapolated end-point energy, and this is the value Friedman and Smith used in computing what they call the neutrino mass. Because of (5) and (6) no information on m_ν can be obtained from such a procedure. Rather their experiments may be used to check the relation

$$E_e^{extr.} = M_{H^3} - M_{He^3} . \tag{7}$$

Thanks to parity nonconservation, from an accurate measurement of the shape of the β spectrum near the end point we can now estimate a value of the neutrino mass free from the previously encountered theoretical ambiguities.

For instance, the results of Hamilton, Alford, and Gross[2] now imply that the neutrino mass is less than 200 ev whereas in the "old" days the same experimental data were used to set up an upper limit of 500 ev or 150 ev depending on whether we assumed an "even" or "odd" coupling.

We hope that the present note will stimulate further investigations on measurements of the neutrino mass.

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