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LETTERS TO THE EDITOR

SOME OBSERVATIONS ON $\nu_\mu e^- \to \nu_\mu e^-$ SCATTERING AND THE PHOTON-NEUTRINO WEAK COUPLING THEORY

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Recent experiments on $\nu_\mu e^- \to \nu_\mu e^-$ scattering are here investigated on the basis of the photon-neutrino weak coupling theory and the results are found to be in good agreement with the experiments. Finally, it is observed that the theory predicts that the charged-lepton and hadronic neutral current is of pure vector type and a crucial test lies in the detection of the space-time structure of the charged lepton and hadronic neutral current.

Recently several experiments have been performed to estimate the cross section for the reaction $\nu_\mu e^- \to \nu_\mu e^-$ which is typical of a neutral lepton current interaction involving leptons only. The latest experiment by Heisterberg et al.[1)] reports the cross section value $\sigma = (1.40 \pm 0.30) \times 10^{-42}\ E_\nu\,\mathrm{cm}^2$ and $\sin^2 \Theta_W = 0.25 + + {}^{0.07}_{0.05}$, the angle of the detected electrons being $\Theta_e \leq 10$ mrad. Initially Alibran et al.[2a)] reported events where ten isolated e^- were found above 2 GeV. All of them were emitted at an angle smaller than 1.5° with respect to the beam. The incident neutrino energy was in the range 25—200 GeV and the value of the slope

$$S = \sigma_{expt}\,(\nu_\mu e^- \to \nu_\mu e^-)/E_\nu\,(\mathrm{Gev})$$

was always found in the range

$$(0.73^{+0.33}_{-0.26}) \times 10^{-41}\ \mathrm{cm^2/GeV} \leq \mathrm{S} \leq (0.82\,^{+0.37}_{-0.28}) \times 10^{-41}\ \mathrm{cm^2/GeV}.$$

But another recent experiment in Gargamelle by Armenise et al.[2b] (Alibran himself being a member of the group) has reported the cross section value 3 times smaller than that in Ref. 2a on the basis of stricter criteria than those previously adopted. The diminution in cross section magnitude has been ascribed to two reasons: (i) consideration of the effect of bremsstrahlung γ-rays lower the cross section by a factor 1.2 (ii) the remaining factor of 2.6 is apparently due to a large fluctuation which has a probability of 3.0×10^{-3}. Although the latter factor does not seem to be very much convincing the values of the cross section obtained by other experiments[3-8] for $\nu_\mu e^- \to \nu_\mu e^-$ and $\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$ lend support to the diminished value. In this note we shall study the $\nu_\mu e^- \to \nu_\mu e^-$ scattering procces according to the photon-neutrino weak coupling theory[9].

It may be added here that the photon-neutrino weak coupling theory[9] is also a gauge theory which is characterised by the following features; (i) it does not allow any neutral lepton current in weak interactions excepting neutrino current; ii) neutral lepton current in strangeness changing decays are not allowed in this theory and iii) in neutral neutrino current interactions, the neutral charged lepton and hadronic current must be of the vector type. The predictions (i) and (ii) are found to be in excellent agreement with experiments and a crucial test lies in the confirmation of the prediction (iii). It may be remarked here that the recent SLAC experiment of Prescott et al.[10] confirming the parity violation in electron-deutron scattering may be interpreted in terms of the weak interaction of electron with the neutral constituents of hadrons when a certain model of hadron incorporating a lepton-hadron relation is taken into account without involving neutral electron current. This can also simultaneously explain the nonobservance of parity violation in atomic physics[11]. However, it may be pointed out that the recent results of the Harvard-Pennsylvania-Wisconsin collaboration for the neutral current induced inclusive processes establish the fact that the Lorentz character of a hadronic neutral weak current may not be the familiar V-A type of the charged weak currents.

Now to study the pure leptonic processes involving neutral neutrino current we observe that, according to the photon-neutrino weak coupling theory, the vertex involving charged leptons must be of the vector-type as this is purely an electromagnetic vertex. The V-A structure occurs only at the neutrino vertex. Indeed, the process can be depicted according to the following diagram. According to this diagram (Fig. 1), if we calculate the differential cross section, we find

$$\frac{d\sigma}{dt} = \frac{e^2 g^2}{2\pi} \frac{1}{(S - m^2)\, t^2}\, [(S - m^2)^2 + (S + t - m^2)^2 - 2m^2 t]. \qquad (1)$$

Here g is the photon-neutrino weak coupling constant and is taken to be $g \cong 10^{-10}\, e$[8].

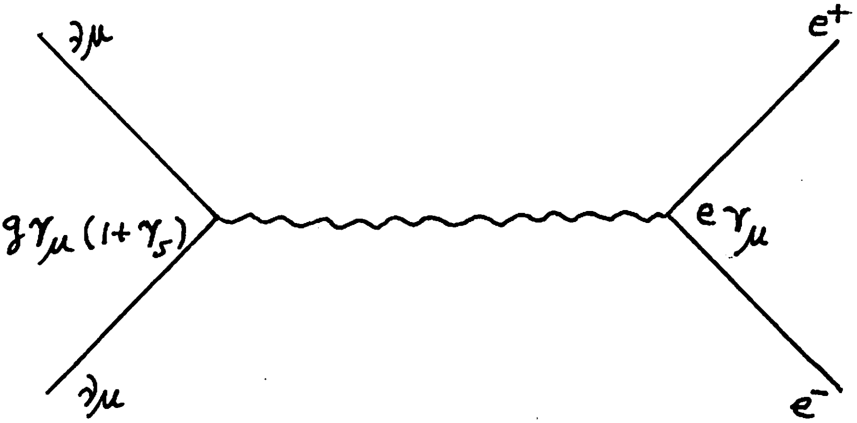

Fig. 1. The process $\nu_\mu e^- \rightarrow \nu_\mu e^-$ according to the photon-neutrino weak coupling theory.

Now it is noted from Eq. (1) that at $q^2 = 0$ (i. e., $t = 0$) the process shows a singular behaviour. In fact, as has been pointed our elsewhere$^{12)}$ at $q = 0$, the nonlocality is destroyed and we will get effectively a point interaction. As this point interaction shows the energy behaviour $\sigma \sim S$ in contrast to the nonlocal interaction mediated by photons when $\sigma \sim \frac{1}{S}$, the experiments where angular distribution is not measured, the point interaction cross section will dominate and we will have effectively $\sigma \sim S$ in conformity with experiments.

The consideration that the behaviour of weak scattering process even at small q^2 region may be different from that in the forward region ($q^2 = 0$) is also indicated by neutrino-nucleon deep inelastic scattering. In fact, in a previous paper$^{13)}$ we have shown that the neutrino-nucleon deep inelastic scattering should satisfy the famous Adler's sum rule

$$\int_0^1 \frac{\mathrm{d}x}{x} \left[\nu W_2 (\bar{\nu} P) - \nu W_2 (\nu P)\right] = 2. \tag{2}$$

Here νW_2 is the conventional structure function. However, it should be pointed out that the experimental indications of the present ep deep inleastic scattering data have put Adler's sum rule in doubt. If we write $\nu W_2 (\nu, q^2) = F(x)$ where $x = q^2/2m_p\nu$ the conserved vector current relation gives

$$F_2^{ep} + F_2^{en} \geq (F_2^{ep} + F_2^{en})_{\text{isovector } \gamma} = \frac{1}{2} (F_2^{\nu p} + F_2^{\bar{\nu} p})_{\text{vector } \Delta S=0}. \tag{3}$$

If we use the electroproduction data, the average of $F_V^{\nu p}, \Delta S = 0$ and $F_V^{\bar{\nu} p}, \Delta S = 0$ never exceeds $0.6 \div 0.7$ in magnitude. Thus it seems unlikely that Adler's sum rule (Eq. 2) will be correct. Sakurai et al.$^{14)}$ have pointed out that for the validity of Adler's sum rule $F^{\nu p}/F^{\bar{\nu} p}$ must be taken $\ll 1$ for $\omega \leq 5$ where $\omega = \frac{1}{x}$. Conventional model calculations which incorporate the sum rule do not have this feature, but instead require very small convergence. In fact, this specific feature suggests that even at small energy transfer region (ν small, $q^2 \neq 0$) νp scattering is highly suppressed and the mechanism is quite different from the region at $q^2 = 0$, however small the energy transfer may be. Since the Gargemelle experiment $\nu_\mu e^- \to \nu_\mu e^-$ scattering involves emission of detected neutrinos and an angle smaller than 1.5°, we can safely take $q^2 \cong 0$ for the process to compare with experiment and as such shall consider point interaction result. However, as the photon neutrino weak coupling theory demands the pure vector nature of hadronic and electron (muon) current, and the neutral neutrino current is simply $\bar{\Phi}_\nu \gamma_\mu \Phi_\nu$ where Φ is a two-component spinor given by

$$\Phi_\nu = \frac{1}{2}(1 + \gamma_5)\Psi_\nu,$$

Ψ_ν being a four-component spinor the point interaction Lagrangian here takes the form

$$\frac{G}{4\sqrt{2}}(\bar{\Psi}_\nu \gamma_\mu (1 + \gamma_5)\Psi_\nu)(\bar{\Psi}_e \gamma_\mu \Psi)$$

where G is the standard four-fermion weak interaction coupling constant. Hence the amplitude here will be 1 $\sqrt{}$h of the standard V-A current-current type interaction. Taking into account this fact, we get

$$\frac{\sigma}{E} = \frac{\sigma_0'}{16}\frac{\text{cm}^2}{\text{MeV}} \tag{4}$$

where

$$\sigma_0' = \frac{4}{\pi}\left(\frac{\hbar}{m_e c}\right)^{-4}\frac{G^2}{m_e^2 c^4} \approx 1.7 \times 10^{-44}\,\text{cm}^2. \tag{5}$$

So we find the slope

$$S = \frac{\sigma}{E_\nu(\text{GeV})} = 0.11 \times 10^{-41}\frac{\text{cm}^2}{\cancel{\text{GeV}}} \tag{6}$$

which agrees very well with the latest result1).

In this context, we may add a few words about $\nu_\mu p$ scattering. In the high energy region we can consider at $q^2 = 0$, the process occurs due to point interaction with the constituents of a proton where the hadronic current must be taken to be of the vector type and at $q^2 \neq 0$ nonclocality must be introduced and we can consider incoherent scattering of the point-like constituents with the virtual photon. Indeed, in an earlier paper11), we have shown that on the basis of a certain model of hadrons, we find

$$R(\nu_\mu) = \frac{\sigma(\nu_\mu N \to \nu_\mu X)}{\sigma(\nu_\mu W \to \mu^- X)} = 0.27 \tag{7}$$

$$R(\bar{\nu}_\mu) = \frac{\sigma(\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu X)}{\sigma(\bar{\nu}_\mu N \rightarrow \mu^+ X)} = 0.41 \tag{8}$$

which are to be compared with the latest experimental values $R(\nu_t) = 0.295 \pm 0.01$ and $R(\bar{\nu}_u) \cong 0.34 \pm 0.03$[15]. The previous CERN data[16] gave $R(\nu_u) \approx 0.21 \pm \pm 0.03$ and $R(\bar{\nu}_u) \approx 0.45 \pm 0.09$. It is interesting to observe that one photon exchange contribution predicts

$$R' = \frac{\sigma(\nu_\mu N \rightarrow \nu_\mu X)}{\sigma(\bar{\nu}_\mu N \rightarrow \bar{\nu}_\nu X)} = 1 \tag{9}$$

at high energy and at high q^2 region where all the charged constituents of a nucleon take part in incoherent scattering with virtual photon and charged current contributions are suppressed enough to show up the neutral current contribution. Using the new experimental data for the ratios $R(\nu_\mu)$ and $R(\bar{\nu}_\mu)$ and together with the enhanced value of

$$R'' = \frac{\sigma(\bar{\nu}_\mu N \rightarrow \mu^+ X)}{\sigma(\nu_\mu N \rightarrow \mu^- X)} \approx 0.6 \text{ beyond 50 GeV}^{17)}$$

we find $R' \cong 1.3$ in close agreement with our prediction. It may be pointed out that for V-A neutral lepton current $R' \approx 3$ and for conventional gauge theories R'' should be constant throughout at all energies having the value $R'' = 0.38$ and thus giving $R' \approx 2.1$.

Finally, we must add that the crucial test of the photon-neutrino weak coupling theory lies in the detection of the vector nature of hadronic and electron (muon) current. Already the experiments on pion production $\bar{\nu} N \rightarrow \bar{\nu} N \pi$ have suggested a good contribution of the isovector hadronic current and it is expected a clean Δ signal will show up in single pion production. Faissner et al.[4] have reported that the experiment on $\nu_\mu e^-$ scattering excludes the V-A structure of the electron current. Though they have remarked that pure V or pure A is unlikely and a mixture of the type V + A is probable, yet further experiments on this is need to have a definite conclusion. Indeed Derrick et al.[18] have concluded from a study of the neutral to charged current ratios that V + A structure is not favoured though pure V or V-A may be accommodate. In view of this, a final check on the space-time structure of the hadronic current in neutral lepton current interactions is desirable to accept or discard the theory.

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ZAPAŽANJA O $\nu_\mu e^- \rightarrow \nu_\mu e^-$ RASPRŠENJU I FOTON-NEUTRINO TEORIJA SLABOG VEZANJA

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Nedavni eksperimenti na $\nu_\mu e^- \rightarrow \nu_\mu e^-$ raspršenju istraženi su u okviru foton-neutrino teorije slabog vezanja i rezultati se slažu sa eksperimentom. Primiječeno je također da teorija predviđa da su nabijene leptonske i hadronske neutralne struje čisto vektorskog tipa i osnovni test leži u detekciji prostorno vremenske strukture nabijene leptonske i hadronske neutralne struje.