Constraints on heavy-lepton mixings from deep-inelastic charged-lepton scattering

A. N. Kamal
Theoretical Physics Institute, University of Alberta, Edmonton, Alberta T6G 2J1, Canada

John N. Ng
TRIUMF and Physics Department, University of British Columbia, Vancouver, British Columbia V6T 1W5, Canada
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The SLAC beam-dump experiment is analyzed to set limits on the neutrino mixing parameters that enter the Salam-Weinberg-type electroweak theory if a heavy neutral lepton exists. Both possibilities for this neutral lepton (a Dirac particle or a Majorana particle) are discussed. Implications for experiments on $\mu^- \to e^+$ conversion in nuclei are also discussed.

I. INTRODUCTION

Recent studies of gauge theories of electroweak interactions have drawn attention to the question of neutrino mass. It is well known that in the standard Weinberg-Salam SU(2) × U(1) gauge theory[1] the neutrinos are arranged *a priori* only in a left-handed[2] doublet, thereby ensuring that they are massless. More recently, a unified gauge theory of electroweak and strong interactions[3] using SU(5) as the unifying group has been proposed with massless neutrinos as a natural consequence of arranging, e.g., e^- and ν_e and the three colored d quarks in the same fundamental representation of SU(5). On the other hand, simple generalization of the Weinberg-Salam theory to more families of leptons and quarks allows for the existence of massive neutral leptons.[4-6] Furthermore, it was pointed out by Pontecorvo[7,8] that the existence of heavy neutral leptons would lead to the mixing of neutrino states, thus giving rise to various lepton-number-violation phenomena, such as $\mu^+ \to e^+\gamma$ and $\mu^- + \text{nucleus} \to e^- + \text{nucleus}$. Thus, it is important to know if heavy neutral leptons exist.

Theoretically, neutral heavy leptons fall into two categories. The first one is of the Dirac type which we shall denote by L^0. They obey the usual Dirac equation with a mass term. The second possibility is that they are Majorana particles denoted by N^0 and defined by $N^{0c} \equiv \mathfrak{C}N^0 = N^0$ where $\mathfrak{C}$ is the charge-conjugation operator. Recently attention has been given to Majorana leptons in unified strong and electroweak gauge theories as a way of ensuring baryon-number conservation and thereby proton stability.[9] Experimentally, the information on Majorana leptons is very scarce. They have been searched for in pion and kaon decays where the limit on their mass is set to be lighter than a few tens of eV/c^2 or heavier than 500 MeV/c^2 if they couple to these hadrons with the full strength of Fermi coupling, G_F.

There exist two classic experiments wherefrom information on N^0 can be inferred, namely, (i) no-neutrino double-β decay of heavy nuclei such as[10]

$$^{130}\text{Te} \to {}^{130}\text{Xe} + 2e^- , \quad (1)$$

and (ii) no-neutrino capture of a μ^- by a nucleus (A, Z) with the emission of an e^+,[11] depicted by

$$\mu^- + (A, Z) \to e^+ + (A, Z-2) . \quad (2)$$

The nonobservation of reactions (1) and (2) sets stringent limits on the possiblity of lepton-number-violating interactions. However, the theoretical estimates of the rates for these processes are plagued with nuclear physics uncertainties.

If all neutral heavy leptons are of the L^0 (Dirac) type, then reactions (i) and (ii) will not occur. However, muon-number-violating reactions such as

$$\mu^- + N \to e^- + N \quad (3a)$$

and

$$\mu^+ \to e^+ \gamma \quad (3b)$$

could still occur. Important information on L^0, which we shall discuss later, is obtained by studying these reactions. We note in passing that N^0 will also induce reactions (3) at the same level as an L^0 would.

In this paper we study a different class of experiments, i.e., deep-inelastic production of L^0 and/or N^0 in electron or muon scattering off hadrons. An example will be the SLAC beam-dump experiment[12] performed several years ago. We analyze this experiment in detail and extract constraints on the weak couplings of heavy leptons of a given mass to electrons and/or muons. We denote the mass of either L^0 or N^0 by M_σ.

To be specific we assume a sequential lepton model given in Ref. 13 where the left-handed leptons are arranged as follows:

$$\begin{pmatrix}\nu_e+\beta N^0\ (L^0)+\cdots\\ e^-\end{pmatrix}_L,\quad \begin{pmatrix}\nu_\mu+\gamma N^0\ (L^0)+\cdots\\ \mu^-\end{pmatrix}_L,\quad \begin{pmatrix}\nu_\tau+\delta N^0\ (L^0)+\cdots\\ \tau^-\end{pmatrix}_L,\quad \begin{pmatrix}N^0\ (L^0)+\cdots\\ N^-\end{pmatrix}_L. \tag{4}$$

The mixing parameters are given by β, γ, and δ. The deep-inelastic production of N^0 (L^0) by electrons is given by (see Fig. 1)

$$e^- + \text{nucleon} \to N^0\ (L^0) + \text{anything}. \tag{5}$$

In order for Eq. (5) to proceed at SLAC energies, M_σ has to be less than about 10 GeV/c^2; otherwise the production rate would be too small to be of interest. We also assume that the charged lepton N^- is the heavier one of the doublet.[14] The neutrino states ν_e and ν_μ will be assumed massless in accordance with current experimental limits of $m_{\nu_e} < 60$ eV/c and $m_{\nu_\mu} < 0.57$ MeV/c^2.[15] The mass of ν_τ need not be taken to be zero; however, most of our discussions will not involve the τ-lepton doublet.

Another important consequence of the model is that the leptonic flavor-changing neutral currents do not exist in the lowest order. This is necessary since the rare decay $\mu^+ \to e^+e^-e^+$ is highly suppressed.

With the model defined above, in Sec. II we estimate the lifetime of N^0 (L^0). In Sec. III we shall calculate the production rate of Eq. (5) at SLAC, folding in the straggling of the electron beam in the target dump. In Sec. IV we discuss our results and some general implications thereof. We also relate them to other experiments, especially those of reactions (1), (2), and (3).

II. ESTIMATES OF THE LIFETIME OF N^0 (L^0)

For clarity we discuss the two cases L^0 and N^0 separately. Some of our results, in the appropriate limits, will coincide with those of Rosner.[16]

The lifetime of N^0 depends crucially on how many lepton doublets occur between the currently six known leptons and the N^0 as well as on the mixing parameters β, γ, and δ. We assume that it is the fourth neutrino; then the semileptonic decay modes are

$$N^0 \to e^+\pi^-,\ e^-\pi^+, e^+\rho^-,\ e^-\rho^+, e^+ + X^-,\ e^- + X^+, \tag{6a}$$

$$\to \mu^+\pi^-,\ \mu^-\pi^+,\ \mu^+\rho^-,\ \mu^-\rho^+,\ \mu^+ + X^-,\ \mu^- + X^+, \tag{6b}$$

$$\to \tau^+\pi^-, \tau^-\pi^+,\ \tau^+\rho^-,\ \tau^-\rho^+,\ \tau^+ + X^-,\ \tau^- + X^+. \tag{6c}$$

The leptonic decay modes are

$$N^0 \to e^+e^-\bar{\nu}_e,\ e^-e^+\nu_e,\ e^+\mu^-\bar{\nu}_\mu,\ e^-\mu^+\nu_\mu,\ e^+\tau^-\bar{\nu}_\tau,\ e^-\tau^+\nu_\tau, \tag{7a}$$

$$\to \mu^+e^-\bar{\nu}_e,\ \mu^-e^+\nu_e,\ \mu^+\tau^-\bar{\nu}_\tau,\ \mu^-\tau^+\nu_\tau,\ \mu^+\mu^-\bar{\nu}_\mu,\ \mu^-\mu^+\nu_\mu, \tag{7b}$$

$$\to \tau^+e^-\bar{\nu}_e,\ \tau^-e^+\nu_e,\ \tau^+\mu^-\bar{\nu}_\mu,\ \tau^-\mu^+\nu_\mu,\ \tau^+\tau^-\bar{\nu}_\tau,\ \tau^-\tau^+\nu_\tau. \tag{7c}$$

In the range of M_σ (<10 GeV/c^2) the decay modes involving the τ lepton are kinematically suppressed. Hereafter, we neglect them.

The partial width for any one of the leptonic modes[16] is easily calculated to be

$$\Gamma(N^0 \to e^+e^-\nu_e) = \frac{\beta^2 G_F{}^2 M_\sigma{}^5}{192\pi^3}. \tag{8}$$

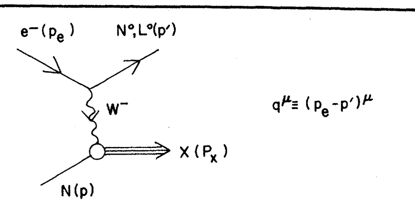

FIG. 1. Feynman diagram for the deep-inelastic production of a neutral heavy Majorana (N^0) or Dirac (L^0) lepton from electron-nucleon scattering. The four momenta are defined in parentheses.

Hence the total leptonic width into e and μ's is

$$\Gamma_l = \frac{(\beta^2+\gamma^2)G_F{}^2 M_\sigma{}^5}{48\pi^2}. \tag{9}$$

The semileptonic width can be estimated by using a simple quark model with three colors.[16] When the mass of the quarks is neglected, the semileptonic width is given by

$$\Gamma_{\rm SL} = \frac{3(\beta^2+\gamma^2)G_F{}^2 M_\sigma{}^5}{96\pi^3}. \tag{10}$$

If the rate is dominated by decays involving light leptons and quarks only then the total width is given by

$$\Gamma^{\rm tot} \simeq 10(\beta^2+\gamma^2)\left(\frac{M_\sigma}{m_\mu}\right)^5 \Gamma_\mu\ , \tag{11}$$

where

$$\Gamma_\mu = \frac{G_F{}^2 m_\mu{}^5}{192\pi^3} = 4.55\times 10^5 \text{ sec}^{-1} \tag{12}$$

is the decay width of the muon.

The above formulas are valid for Majorana leptons within the framework of Weinberg-Salam $SU(2)\times U(1)$ gauge theory, where the left-handed leptons are put in doublets and right-handed ones are given singlet assignments.

We note that similar equations hold for the case of a right-handed N^0 arranged together with a muon, say, in a doublet $(N^0\mu^-)_R$ which strictly speaking is not ruled out by current data. However, for this case the two-body decay into a photon and an ordinary neutrino becomes non-negligible.[17] In general all these will add to the total width given by Eq. (11), thus leading to a longer-lived Majorana lepton than the example we are considering.

The previous discussion can easily be adapted to the case of L^0. First, if the L^0 is assigned to N^- in a doublet, then the decay modes are just the even entries of Eqs. (6) and (7). A different assignement is also possible, namely, $\bar{L}^0$ the antiparticle is partner to N^- in a doublet. For this, one may replace $N^0\to\bar{L}^0$ and the odd entries of Eqs. (6) and (7) will occur. The width estimates of Eqs. (8)–(11) will have to be divided by a factor of 2 for the L^0 or $\bar{L}^0$.

In the next section we calculate the production of N^0 and L^0 in deep-inelastic charged-lepton–hadron scattering. As the difference between N^0 and L^0 is not relevant, our discussion will be in terms of N^0 only.

III. DEEP-INELASTIC PRODUCTION OF NEUTRAL HEAVY LEPTONS AND THE SLAC BEAM-DUMP EXPERIMENT

Here we calculate the possible production of N^0 in the SLAC beam-dump experiment (see Ref. 12 for details).

The reaction and its kinematics are shown in Fig. 1. The differential cross section is calculated to be

$$\frac{d^3\sigma}{dE'd\Omega'} = \frac{|\vec{p}'|}{8\pi^2 ME} G_F{}^2\beta^2\left\{(Q^2+M_\sigma{}^2)W_1 + \tfrac{1}{2}W_2\left[4E\left(E-\frac{\nu}{M}\right)-(Q^2+M_\sigma{}^2)\right] - \frac{W_3}{2M^2}[2MEQ^2-\nu(M_\sigma{}^2+Q^2)] + \frac{M_\sigma{}^2}{M^2}\left[\tfrac{1}{2}(M_\sigma{}^2+Q^2)W_4 - MEW_5\right]\right\}, \tag{13}$$

where $Q^2\equiv-(p_e-p')^2$ and $\nu\equiv p\cdot q$. The usual deep-inelastic structure functions[18] are represented by W_i $(i=1,\ldots 5)$ which by time-reversal invariance are real. The conserved-vector-current hypothesis implies $W_4=0$, and using Bjorken scaling we have

$$W_1 = F_1(x),$$

and

$$\frac{\nu W_i}{M^2} = F_i(x), \quad i=2,\ldots 5$$

where

$$x = \frac{Q^2}{2\nu}.$$

With the further assumption of the Callan-Gross relations[19]

$$F_2(x) = 2x F_1(x) = xF_5(x) = -xF_3(x), \tag{14}$$

we can reduce Eq. (13) to

$$\frac{d^3\sigma}{d\Omega' dE'} = \frac{\beta^2 G_F{}^2|\vec{p}'|}{8\pi^2 ME}\nu W_2 \times\left\{\frac{\nu}{M^2}\frac{Q^2+M_\sigma{}^2}{Q^2} + \frac{1}{2}\left(\frac{4E^2}{\nu}-\frac{4E}{M}-\frac{Q^2+M_\sigma{}^2}{\nu}\right) + \frac{1}{Q^2M^2}[Q^2(2ME-\nu)-\nu M_\sigma{}^2] - \frac{2E}{M}\frac{M_\sigma{}^2}{Q^2}\right\}. \tag{15}$$

When $M_\sigma{}^2\to 0$, Eq. (15) reduces to the usual deep-inelastic neutrinos cattering formula in the scaling limit.[20]

Equation (15) can be further simplified for beam-dump experiments by noting that $Q^2/E^2\ll 1$ due to the small production angles involved. Thus, we obtain

$$\frac{d^3\sigma(E)}{d\Omega' dE'} = \frac{\beta^2 G_F{}^2|\vec{p}'|}{4\pi^2 M}EW_2\left[1-\frac{M_\sigma{}^2}{Q^2}\left(1-\frac{E'}{E}\right)\right] \tag{16}$$

and

$$Q^2 \simeq EE'\left[\frac{M_\sigma{}^2}{E'^2}\left(1-\frac{E'}{E}\right)+\theta'^2\right],$$

where θ' is the production angle defined with respect to the beam direction. Since we are considering deep-inelastic scattering we can take $|\vec{p}'|\simeq E'$. The angular dependence is all contained in νW_2 which for simplicity is chosen to have the form[21]

$$\frac{\nu W_2}{M^2}\equiv xf(x)=3.6\sqrt{x}\,(1-x)^3+0.2(1-x)^4\,. \qquad (17)$$

Since the maximum production angle is only several milliradians, we can integrate Eq. (16) over the angle to obtain the result

$$\sigma(E)=\frac{\beta^2 G_F{}^2E^2}{2\pi}\,\theta_0{}^2\left\{(0.1)\left[\ln\left(\frac{E}{M}-1\right)\right]+1.2\theta_0\left[\sqrt{2}\left(\frac{E}{M}\right)-\frac{13}{5}\left(\frac{E}{2M}\right)^{1/2}\right]\right\}, \qquad (18)$$

where $\theta_0\simeq 0.044$ rad for the SLAC experiment. Note that the energy dependence is higher than linear which reflects the experimental cut of accepting only production in the forward direction. Equation (18) then allows us to estimate the total production cross section including the straggling of the primary electron beam as it goes through the target of thickness T in units of radiation lengths. The results of Ref. 22 indicate that one needs only to consider first-generation electrons. The intensity $I(t,E)$ of the beam at a distance t radiation lengths is accurately given by[22]

$$I(t,E)=\frac{1}{E_0}\,\frac{(\ln E_0/E)^{(4t)/3-1}}{\Gamma(\frac{4}{3}t)}, \qquad (19)$$

where E_0 is the maximum beam energy. We take $E_0=20$ GeV for our numerical calculations. The total number n of N^0's produced is obtained by convoluting $I(t,E)$ with $\sigma(E)$. Thus

$$n=n_0\int_0^T dt\,\frac{1}{\Gamma(\frac{4}{3}t)}\int_{E_{\min}}^{E_0} dE\,\sigma(E)I(t,E) \qquad (20)$$

and

$$n_0=\frac{0.624\rho_0X_0N_a}{A}\times 10^{-27}, \qquad (21)$$

where ρ_0 is the total number of electrons used, X_0 is the unit radiation length of the target material, N_a is the Avagadro's number, and A is the atomic number of the target. The minimum energy $E_{\min}$ for production depends on the mass of the Majorana lepton. An accurate evaluation will involve numerical integration. Putting in the experimental values of 20 C of charge dumped into the target of the SLAC experiment, we obtain the total number of N^0 produced in both water and aluminum dump as

$$n=4.8\times 10^5\beta^2 \qquad (22)$$

into the solid angle subtended by the detector. This number is good for $M_\sigma<5$ GeV/c^2. The production of a lepton heavier than this is substantially suppressed at SLAC.

Next we examine how this production rate relates to the parameters that describe the Majorana leptons. Consider first the case of a long-lived lepton such that most of the N^0's produced at the dump pass through the rock shielding and interact weakly at the detector via a scattering process. The SLAC experiment sets a limit on detectability given by[12]

$$\sigma_{\rm prod}\sigma_{\rm int}f_\Omega f_{\rm tr}\lesssim 10^{-70}\ {\rm cm}^4\,, \qquad (23)$$

where $\sigma_{\rm prod}$ is the production cross section, $\sigma_{\rm int}$ is the interaction cross section, f_Ω is the ratio of the production to detector solid angle, and $f_{\rm tr}$ is the transmission probability. For long-lived particles, $f_{\rm tr}\simeq 1$. The quantity $\sigma_{\rm prod}$ is given by Eq. (13) and estimated to be

$$\sigma_{\rm prod}\simeq 2\times 10^{-36}\beta^2\,. \qquad (24)$$

We can take $\sigma_{\rm int}$ to be a typical weak-interaction cross section

$$\sigma_{\rm int}\simeq 10^{-38}\times E'\,{\rm cm}^2\,, \qquad (25)$$

where E' is the energy of N^0. With $f_\Omega\simeq 0.2$, we find

$$2\times 10^{-74}\beta^2\lesssim 10^{-70} \qquad (26)$$

using $E'\simeq\frac{1}{2}E\simeq 10$ GeV. This does not provide a useful constraint on β^2.

As a second case consider a short-lived N^0. An interesting situation occurs when some of the N^0's decay in the rock shielding and the decay muons reach the detector. To simplify our calculations we first calculate the average energy of the produced N^0's to be $\langle E'\rangle\simeq 0.43E_0=8.6$ GeV. From this the mean decay length l_0 in meters is calculated to be

$$l_0=\frac{\langle E'\rangle}{M_\sigma}\,\tau_0c=\frac{567}{(\beta^2+\gamma^2)}\left(\frac{m_\mu}{M_\sigma}\right)^5\frac{1}{M_\sigma}\,, \qquad (27)$$

where τ_0 is the mean life in seconds computed from Eqs. (11) and M_σ is expressed in units of GeV. The range of a 9-GeV muon[23] in rock of density 2 g/cm^3 is about 25 m. Thus the muons produced by the decay of the heavy leptons in the last 25 m of the rock could reach the detector. The number of heavy leptons decaying in the last 25 m of rock is

$$n\int_{30}^{55}\frac{dl}{l_0}\,e^{-l/l_0}\,. \qquad (28)$$

If we interpret the SLAC experimental result to be negative, i.e., that all observed events are accounted for by standard mechanisms, then we arrive at the constraint equation

$$1 - e^{-25/t_0} \lesssim \frac{1}{n}\frac{e}{B}\,, \tag{29}$$

where B is the branching ratio into muons and is given by

$$B \simeq \frac{\beta^2 + 5\gamma^2}{5(\beta^2+\gamma^2)}\,. \tag{30}$$

Putting Eqs. (27) and (30) into Eq. (29) we get

$$1 - \exp[-\overline{M}_\sigma(\beta^2+\gamma^2)/23] \lesssim \frac{5(\beta^2+\gamma^2)\times 10^{-5}}{4.8\beta^2(\beta^2+5\gamma^2)}\exp[\overline{M}_\sigma(\beta^2+\gamma^2)/19]\,, \tag{31}$$

where

$$\overline{M}_\sigma = \left(\frac{M_\sigma}{M_\mu}\right)^5 M_\sigma\,. \tag{32}$$

Equation (30) holds for Marjorana leptons.

The case of L^0 is similar. Notice first that the branching ratio into at least one muon is also given by Eq. (30). Only the lifetime is doubled. Hence the corresponding equation for L^0 is

$$1 - \exp[-\overline{M}_\sigma(\beta^2+\gamma^2)/46] \lesssim \frac{1.04(\beta^2+\gamma^2)\times 10^{-5}}{\beta^2(\beta^2+5\gamma^2)}\exp[M_\sigma(\beta^2+\gamma^2)/38]\,. \tag{33}$$

Equations (31) and (33) can be solved in the two-dimensional parameter space for β and γ. In general, for a given value of γ there are two allowed regions for β and vice versa. In Figs. 2 and 3 we show the solutions of Eq. (31) (Majorana N^0) and Eq. (33) (Dirac L^0), respectively. The solid curves are drawn for the case $M_\sigma = 0.5$ GeV/c^2 and dashed curves for $M_\sigma = 0.8$ GeV/c^2. The region between the curves is the disallowed region. For example, the region between the two solid lines in Fig. 2 is the situation where a 500-MeV/c^2 N^0 would induce at least a one or more pronged event in the SLAC detector. Hence, the values of β^2 and γ^2 outside the confines of this line are allowed for a 500-MeV/c^2 lepton. In particular for a 500-MeV/c^2 Majorana lepton, the value of $\beta^2 = 2\times 10^{-3}$ obtained from a simple estimate made in no-neutrino double-β decay[24] would imply that $\gamma^2 \gtrsim 0.12$ in order to be consistent with the interpretation of the SLAC experimental result as being null.

It is quite clear from Figs. 2 and 3 that values of β^2 and γ^2 excluded by the SLAC experiment shrink quite rapidly as M_σ increases. In fact, for a 1.5-GeV/c^2 N^0 or L^0 practically all values of β^2 and γ^2 are allowed by the SLAC experiment.

We note in passing that even when the heavy lepton does not mix with ν_μ, i.e., $\gamma^2 = 0$, the experiment excludes the region $3.8\times 10^{-4} \lesssim \beta^2 \lesssim 0.15$ for a 500-MeV/c^2 Majorana lepton.

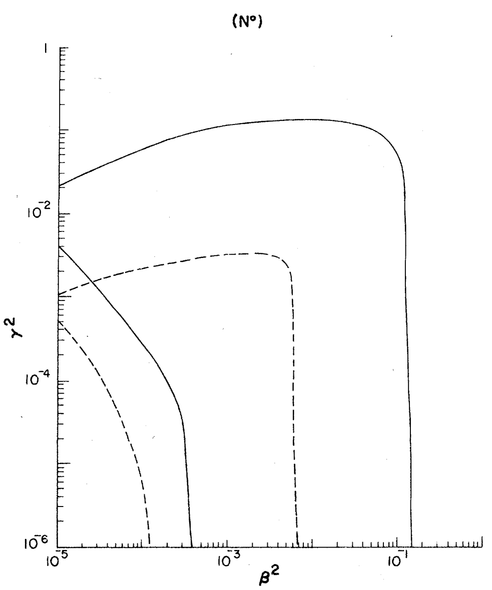

FIG. 2. Solution of Eq. (31) for the Majorana case (N^0). The solid curves are for $M_\sigma = 0.5$ GeV/c^2 and the dashed curves for $M_\sigma = 0.8$ GeV/c^2. The forbidden region is between the curves.

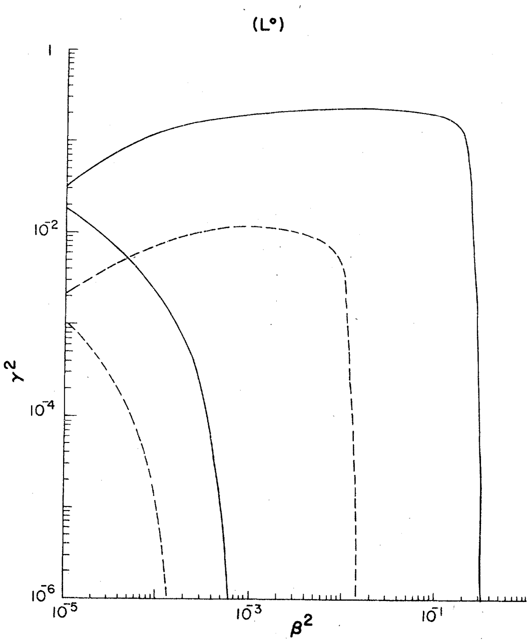

FIG. 3. Solution of Eq. (33) for the Dirac case (L^0). Solid curves are for $M_\sigma = 0.5$ GeV/c^2 and the dashed curves for $M_\sigma = 0.8$ GeV/c^2. The forbidden region is between the curves.

Further implications of these bounds are discussed in the next section.

IV. DISCUSSION

It is clear from the inequalities of Eqs. (31) and (33) that as M_σ increases, both β and γ have to decrease in order to satisfy the inequalities. There is evidence[13,24] from the neutrinoless double-β decay [reaction (1)] that $\beta^2 \lesssim (1-2)\times 10^{-3}$ for M_σ between 0.5 and 1.0 GeV/c^2. Our analysis shows that for a Majorana-type neutrino (N^0) with mass $M_\sigma = 0.5$ GeV/c^2 if $\beta^2 \simeq 10^{-3}$, then $0.1 < \gamma^2 \leq 1$. For $(\beta\gamma)^2 \simeq 10^{-3}$ we had earlier estimated[13] the branching ratio for $\mu^- \to e^+$ on nuclei to be $\sim 10^{-14}$ with respect to normal muon capture. The current solution of $\gamma^2 \gtrsim 0.1$ is consistent with this estimate. However, if an improved experiment or calculation on (1) reduces β^2 to less than 10^{-4}, then the lower branch $\gamma^2 < 10^{-4}$ will lower the branching-ratio estimate to $\ll 10^{-19}$. Corresponding statements could be made for $M_\sigma = 0.8$ GeV/c^2. For $\beta^2 \simeq 10^{-3}$ the high γ^2 solution is $2\times 10^{-3} < \gamma^2 \leq 1$. Thus our optimistic estimate[13] for anomalous muon capture with $M_\sigma = 0.8$ GeV/c^2 could well be lowered by three orders of magnitude.

We wish to emphasize that the SLAC beam-dump experiment has a N^0-production mechanism which depends on the (ν_e-N^0) mixing parameter β. A similar beam-dump experiment with a muon beam would generate N^0's via the (ν_μ-N^0) mixing parameter γ. The inequalities analogous to Eq. (31) would also produce useful constraints.

All the above arguments can be repeated for the Dirac-type lepton (L^0, see Fig. 3). The resulting constraints would be relevant to $\mu^- + N \to e^- + N$ [reaction (3a)].

Although our knowledge of the Majorana leptons is very meager, we see that the set of experiments (1)–(3) taken together do give us an indication of the strengths of their mixing with ordinary neutrinos.

We conclude by mentioning that our considerations hold in general for any Majorana lepton that couples weakly to the ordinary charge leptons, since only the weak coupling strength and the mass of the particle play a role in our calculations. New beam-dump experiments will certainly be important to ascertain the existence or the properties of these leptons.

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