Limits on the mass of the right-handed Majorana neutrino

Rabindra N. Mohapatra
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742
(Received 28 May 1986)

We derive limits on the mass of the right-handed Majorana neutrino (N_R) in terms of the mass of the right-handed W_R boson in left-right-symmetric theories of weak interactions from the recent results on lifetime for neutrinoless double-β decay of ^{76}Ge as well as from theoretical considerations of vacuum stability.

One of the new particles that is required for the consistency of the left-right-symmetric models[1] of weak interactions is the right-handed neutrino. Understanding of the small mass of the left-handed neutrino requires that the right-handed neutrino have large Majorana mass.[2,3] The value of the mass depends on two parameters: (a) the Yukawa coupling of the right-handed Higgs multiplets[3] Δ_R and (b) the mass of the right-handed W_R boson. Phenomenologically this value can be anywhere from a few Gev (Ref. 4) to as large as, or perhaps larger than, the mass of the right-handed W_R boson. An extensive study of the phenomenological constraints on the mass of the right-handed neutrino has been given by Gronau, Leung, and Rosner.[4] Our goal in this paper is more modest and should be taken as a supplement to the work of Ref. 4. We consider limits on the mass of the right-handed neutrino (N_R) from two considerations: (a) theoretical considerations of vacuum stability and (b) most recent data[5] on the neutrinoless double-β decay of ^{76}Ge.[6] In both cases, we correlate the mass of the right-handed neutrino with that of the W_R boson.

BOUND ON M_{N_R} FROM VACUUM STABILITY

It is well known from the works of Coleman and E. Weinberg[7] that one-loop corrections to the tree-level potential in a gauge theory can affect the picture of spontaneous symmetry breaking and lead to vacuum instability unless the parameters of the theory are restricted to a limited range. These considerations have been utilized to obtain lower bounds on the Higgs-boson mass[8] as well as to obtain upper bounds on the fermion masses[9] in the standard model. In this note, we use the same techniques to limit the mass of the right-handed neutrino.

To carry out our derivation, we remind the reader that the right-handed neutrino mass owes its origin to the Higgs mesons[3] $\Delta_L(3,1,2)+\Delta_R(1,3,2)$ with transformation properties under $SU(2)_L\times SU(2)_R\times U(1)_{B-L}$ group indicated within parentheses. Denoting the leptonic doublets by $\psi_L\equiv(\nu_L,e_L^-)$ and $\psi_R\equiv(N_R,e_R^-)$, the relevant Yukawa coupling can be denoted by

$$\mathcal{L}_Y=h[\psi_L^T C^{-1}\tau_2\Delta_L\psi_L+(L\leftrightarrow R)]+\text{H.c.}\ , \tag{1}$$

where

$$\Delta_L=\begin{pmatrix}\Delta^+ & \Delta^{++}\\ \Delta^0 & \Delta^+\end{pmatrix}_L\ ,$$

and similarly for $L\leftrightarrow R$. The $B-L$ as well as the $SU(2)_R$ symmetry are broken by $\langle\Delta_R^0\rangle=V_R\neq0$. This gives mass to the W_R and Z_R boson, i.e., $M_{W_R}=gV_R$ as well as to the right-handed neutrino N_R: $M_{N_R}=hV_R$. The Higgs potential involving the Δ_L and Δ_R receives one-loop contributions from the gauge and Yukawa couplings as

$$V^{(1\text{ loop})}=\left(\frac{3}{64\pi^2}[\tfrac{1}{2}g^4+(g^2+g'^2)^2]-\sum_{i=e,\mu,\tau}\frac{h_i{}^4}{64\pi^2}\right)\times(\Delta_R^{0+}\Delta_R^0)^2\ln\Delta_R^{0+}\Delta_R^0+(R\to L)\ , \tag{2}$$

where we have suppressed the Δ^{++}, Δ_R^+ terms since they do not play any role in the symmetry breaking and g' represents the $U(1)_{B-L}$ coupling. We have also ignored the contribution of Higgs-boson self-couplings λ to $V^{1\text{ loop}}$. It is clear that vacuum stability requires that

$$\sum_{i=e,\mu,\tau} h_i{}^4\le3[\tfrac{1}{2}g^4+(g^2+g'^2)^2]\ . \tag{3}$$

Using the fact that $g=e\cos\theta_W$ and $g'=e\sqrt{\sec2\theta_W}$, we

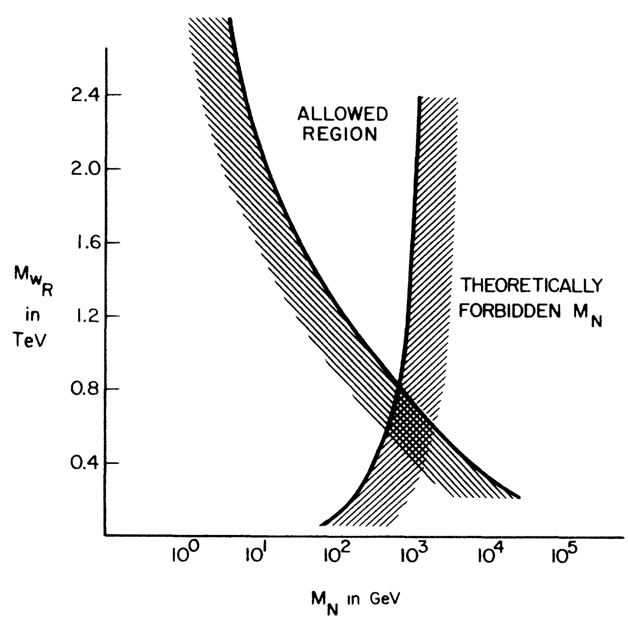

FIG. 1. Allowed values for the M_{W_R} and M_{N_R} from recent results on neutrinoless double-β decay and vacuum stability.

find that

$$\left[\sum_i M_{N_{R,i}}{}^4\right]^{1/4} \leq 0.95 M_{W_R} \ , \tag{4}$$

where we used $\sin^2\theta_W = 0.22$. This is our main result. The main uncertainty in this inequality comes from lack of knowledge of the Higgs-boson self-coupling λ; if we assume it to be one, the bound becomes

$$\left[\sum_i M_{N_{R,i}}{}^4\right]^{1/4} \leq 1.18 M_{W_R} \ . \tag{5}$$

Furthermore, if right-handed neutrinos of all three generations have the same mass, then we can bound that mass $M_N \leq 0.9 M_{W_R}$ using Eq. (5). In Fig. 1, we plot this upper limit on a semilogarithmic scale.

CONSTRAINTS FROM NEUTRINOLESS DOUBLE-β DECAY

It was pointed out in Refs. 3 and 10 that neutrinoless double-β decay[11] gets additional contributions from heavy right-handed neutrino intermediate states in left-right-symmetric models. There are basically two kinds of contributions:[12] one that involves two W_L exchanges and the other that involves the exchange of two W_R bosons. In the first case, the amplitude is proportional to

$$M^{LL} \approx G_F{}^2 \xi^2 M_N \left\langle \frac{e^{-M_N r}}{r} \right\rangle_{\rm nuc}, \text{ where } \xi \simeq \left(\frac{M_e}{M_N}\right), \tag{6}$$

whereas in the second case it is given by

$$M^{RR} \approx G_F{}^2 (M_{W_L}/M_{W_R})^4 M_N \left\langle \frac{e^{-M_N r}}{r} \right\rangle_{\rm nuc} \ . \tag{7}$$

For M_N in the GeV range, $\xi^2 \simeq 2.5\times10^{-8}/(M_N \text{ in GeV})^2$ and M^{LL} is then negligible compared to M^{RR} for $M_{W_R} \leq 20$ TeV. The estimate of the nuclear matrix element has been reviewed in Ref. 11. Using the latest experimental results we can limit the right-handed neutrino mass in terms of the W_R mass. This is done in Fig. 1. The region to the left of the left line (the shaded area) is forbidden by the latest neutrinoless double-β decay results.

There are also limits on the $0^+ \rightarrow 2^+$ transitions that arise in left-right-symmetric models. Their typical strength is of order

$$M_{LR} \approx G_F{}^2 \xi \left(\frac{M_{W_L}}{M_{W_R}}\right)^2 \ . \tag{8}$$

Ejiri *et al.* have the best bound on this lifetime[6] of $0^+ \rightarrow 2^+$ transition in ^{76}Ge to be $> 4.6\times10^{22}$ years which implies $\xi(M_{W_L}/M_{W_R})^2 \leq 1.6\times10^{-5}$. For $M_N \gtrsim 2$ GeV and $M_{W_R} \geq 0.8$ TeV, $\xi(M_{W_L}/M_{W_R})^2 \leq 0.2\times10^{-5}$. Therefore, no new constraints on M_{N_R} emerge from this decay mode.

One important implication of this analysis is that for lower M_{W_R} the right-handed neutrino must be heavier; for instance, $M_{W_R} \gtrsim 2$ TeV implies $M_{N_R} \gtrsim 17$ GeV or so, and $M_{W_R} \approx M_{N_R}$ at $M_{W_R} \simeq 0.8$ TeV.

In summary, we have obtained limits on the mass of the right-handed neutrino in terms of the mass of the right-handed W_R boson, which will be of phenomenological interest in the analysis of left-right-symmetric models. Our result is based on the theoretical input that uses vacuum stability arguments at the one-loop level and the latest experimental results on neutrinoless double-β decay. It may be noted that there exist other constraints on the M_{N_R} masses in the MeV range from cosmological considerations[13] as well as weak decay processes.[4] The new constraints of this paper are complementary to these.

This work was supported by a grant from the National Science Foundation.

[1]J. C. Pati and A. Salam, Phys. Rev. D **10**, 275 (1974); R. N. Mohapatra and J. C. Pati, *ibid.* **11**, 566, 2558 (1975); G. Senjanovic and R. N. Mohapatra, *ibid.* **12**, 1502 (1975).

[2]M. Gell-Mann, P. Ramond, and R. Slansky, *Supergravity*, edited by D. Freedman *et al.* (North-Holland, Amsterdam, 1980); T. Yanagida, KEK report, 1979 (unpublished).

[3]R. N. Mohapatra and G. Senjanovic, Phys. Rev. Lett. **44**, 912 (1980); Phys. Rev. D **23**, 165 (1981).

[4]J. Rosner, Nucl. Phys. **B248**, 503 (1984); M. Gronau, C. Leung, and J. Rosner, Phys. Rev. D **29**, 2539 (1984); F. J. Gilman, Comments Nucl. Part. Phys. (to be published); M. Gronau and R. Yahalom, Nucl. Phys. **B236**, 233 (1984).

[5]T. Ejiri *et al.*, Nucl. Phys. **A448**, 271 (1986); D. Caldwell *et al.*, Phys. Rev. D **33**, 2737 (1986).

[6]E. Fiorini *et al.*, Phys. Lett. **121B**, 72 (1983); F. Avignone *et al.*, Phys. Rev. Lett. **50**, 721 (1983).

[7]S. Coleman and E. Weinberg, Phys. Rev. D **7**, 1888 (1973).

[8]S. Weinberg, Phys. Rev. Lett. **36**, 294 (1976); A. Linde, Zh. Eksp. Teor. Fiz. **23**, 64 (1976) [JETP Lett. **23**, 73 (1976)].

[9]P. Q. Hung, Phys. Rev. Lett. **42**, 873 (1979); S. Wolfram and H. D. Politzer, California Institute of Technology report, 1979 (unpublished).

[10]Riazuddin, R. E. Marshak, and R. N. Mohapatra, Phys. Rev. D **24**, 1310 (1981).

[11]For recent reviews, see W. Haxton and G. Stephenson, Jr., Prog. Part. Nucl. Phys. **12**, 409 (1984); M. Doi, T. Kotani, and E. Takasugi, Prog. Theor. Phys. (Suppl.) **83**, 1 (1985); J. D. Vergado, Phys. Rep. **133**, 1 (1986).

[12]This point has also been reemphasized recently by B. Kayser, in *Proceedings of the Oregon Meeting,* the Annual Meeting of the Division of Particles and Fields of the American Physical Society, Eugene, 1985, edited by R. C. Hwa (World Scientific, Singapore, 1986).

[13]S. Sarkar, Rutherford Laboratory Report No. RAL-85-115 (unpublished).