FERMILAB-PUB-92/ 56 -T
NUHEP–TH–92/2
UICPHY–TH/92–6

Comment on "Mechanism for large neutrino magnetic moments"

K. S. Babu[(a)], D. Chang[(b,c)], W.–Y. Keung[(c,d)], and I. Phillips[(b)]

[(a)] *Bartol Research Institute, University of Delaware, Newark DE 19716*

[(b)] *Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208*

[(c)] *Fermi National Laboratory, P.O. Box 500, Batavia, IL60510*

[(d)] *Physics Department, University of Illinois at Chicago, IL 60680*

(Received February 19, 1992)

We show that the simple Zee Model of the neutrino mass already incorporates the interesting prediction of a large transitional neutrino magnetic moment.

PCAS numbers: 13.40.Fn, 12.15Cc, 14.60.Gh, 96.60.Kx

In an inspiring Letter[1], Barr, Freire and Zee (BFZ) consider a spin mechanism which provides for a large neutrino transitional magnetic moment μ_ν but a relatively small neutrino mass. The mechanism can be understood[1] on the basis of an approximate custodial flavor symmetry $SU_\nu(2)$ between the electron and the muon species. Such a symmetry[2] forbids neutrino from being massive while allowing μ_ν. In Standard Model, when the Yukawa couplings associated with the electron and muon masses are set to zero, an $SU_\nu(2)$ symmetry of this type automatically arises. It is therefore tempting to take advantage of such accidental approximate symmetry even in an extension of Standard Model with lepton number breaking. The idea is very appealing because it ties up the smallness of the masses of the neutrinos (with large magnetic moments) with that of the Yukawa couplings of electron and muon. Of course, to generate μ_ν, we need the lepton number symmetry breaking, which has to be implemented within the sector where the custodial symmetry is preserved.

The essential ingredients mentioned above are all realized in a simple model for the neutrino mass proposed by Zee[3] some years ago. The model used one charged $SU_L(2)$-singlet, h^+ and two doublets of Higgs, $\phi_i, i = 1, 2$. However, in the simplest model provided by BFZ, three doublets are introduced to circumvent a technical problem in generating two loop graphs for neutrino magnetic moments. In this note, we wish to point out that the minimal Zee model is indeed sufficient to produce, at the two loop level, a transitional magnetic moment as large as that in the BFZ model.

To keep track of the essentials, we should analyze the model in the limit of vanishing ordinary Yukawa couplings for charged leptons and examine possible assignments of lepton number. As usual in the Zee Model, one can assign two units of lepton number to h^+. Without loss of generality one can choose a basis in which $\langle\phi_1\rangle \neq 0$ and $\langle\phi_2\rangle = 0$. In that case, the cubic coupling $M_{12}h^+(\phi_1^-\phi_2^0 - \phi_2^-\phi_1^0)$ suggests that one should assign two units of lepton number to ϕ_2 and none to ϕ_1. However that does not mean the lepton number is exact even in this limit. It is in fact broken by the Higgs quartic self-interaction of the form $\lambda\phi_2^\dagger\phi_2\phi_2^\dagger\phi_1$ where λ is the coupling constant. Note that this quartic coupling is consistent with the assumption about vacuum expectation values made above. An alternative source of lepton number breaking is the couplings of ϕ_2 to the quark sector.

With these ingredients in place one can go ahead and construct the two loop graphs that contribute to the magnetic moment. The diagrams (in Fig.1) are in fact very similar to the ones BFZ found in the extended model. However, it is important to note that the cubic coupling M_{12} with nonvanishing $\langle\phi_1\rangle$ gives rise to a tree level mixing between the charged boson h^+ and the charged component ϕ_2^+. Therefore one can use the Fig. 3(a) of BFZ with the modification that the h^+ propagator is turned into ϕ_2 by an $\langle\phi_1\rangle$ insertion. Then, at the trilinear bosonic vertex one uses the quartic coupling λ mentioned above with another $\langle\phi_1\rangle$ insertion at the vertex. The Higgs boson loop is then a purely ϕ_2 loop without further insertions. The estimate of this diagram is the same as the one in Eq.(1) of Ref[1], except that the Higgs mass in the formula should be properly reinterpreted. There is also a diagram which uses the lepton number breaking effects in the quark sector mentioned above. One can simply replace the ϕ_2 loop described above by the quark (presumably t and b quarks) loop[4]. The order of magnitude of this contribution is not very different from the previous one. We wish to emphasize that since one can define the custodial $SU_\nu(2)$ symmetry to transform only the leptons, both the quartic coupling λ and the $t\bar{b}$ Yukawa couplings are insensitive to it. All the qualitative discussions about the spin mechanism in Ref[1] can also be illustrated equally well in this simpler model.

The analysis regarding neutrino mass is very similar to those in Ref[1,3]. The natural value for the one loop $e-$ or $\mu-$neutrino masses is around 300 eV, which means we need a mild fine–tuning for the ϕ_2 Yukawa coupling at the level of one or two orders of magnitude. Unfortunately, unlike the BFZ model, there is no option of imposing a discrete symmetry to get rid of the one loop contribution to the neutrino mass. In fact this can be considered as the main motivation for introducing a third doublet. We wish to add that it is in general possible to have the electron and muon neutrinos forming a Dirac particle by imposing ZKM symmetry[5] on the theory. The symmetry can help reduce the mass difference between neutrinos to zero. In addition, it will automatically kill the tree level flavor changing neutral Higgs coupling and the decay $\mu \to e\gamma$ which is strongly constrained experimentally.

We wish to thank R. Barbieri, R.N. Mohapatra, P. Pal, G. Senjanoviċ and L. Wolfenstein for numerous discussions of the BFZ model. This work was supported by the U.S. Department of Energy.

[1] S.M. Barr, E.M. Friere and A. Zee, Phys. Rev. lett. **65**, 2626 (1990).

[2] M.B. Voloshin, Yad. Fiz. **48**, 804 (1988) [Sov. J. Nucl. Phys. **48**, 512 (1988)].

[3] A. Zee, Phys. lett. **93B**, 389 (1980); **161B**, 141 (1985).

[4] This diagram was pointed out recently in K.S. Babu, Maryland Preprint UMD-PP-92-022.

[5] Ya. B. Zeldovich, Dokl. Akad. Nauk. SSSR. **86**, 505 (1952); E.J. Konopinski and H. M. Mahmoud, Phys. Rev. **92**, 1045 (1953).

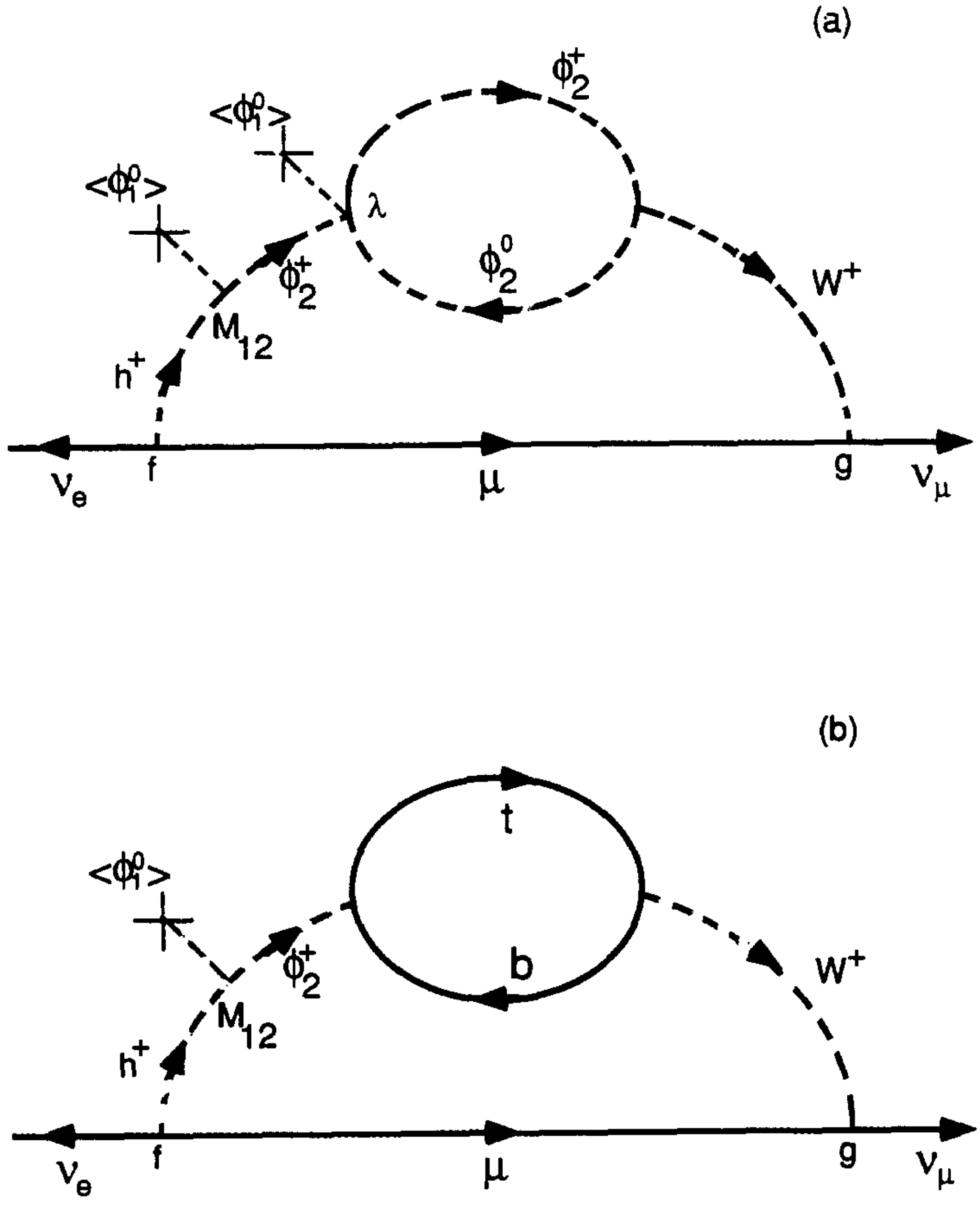

Fig. 1 Typical diagrams for the neutrino transitional magnetic moment, via the Higgs quartic coupling (a) or the quark coupling (b).