NEUTRINO MASSES WITHOUT SEESAW MECHANISM IN A SUSY SU(5) MODEL WITH ADDITIONAL $\bar{5}'_L + 5'_L$

YOSHIO KOIDE

Department of Physics, University of Shizuoka
52-1 Yada, Shizuoka, Japan 422-8526
E-mail: koide@u-shizuoka-ken.ac.jp

A radiatively-induced neutrino mass matrix with a simple structure is proposed on the basis of an SU(5) SUSY GUT model with R-parity violation. The model has matter fields $\bar{5}'_L + 5'_L$ in addition to the ordinary matter fields $\bar{5}_L + 10_L$ and Higgs fields $H_u + \overline{H}_d$. The R-parity violating terms are given by $\bar{5}_L\bar{5}_L 10_L$, while the Yukawa interactions are given by $\overline{H}_d\bar{5}'_L 10_L$. Since the matter fields $\bar{5}'_L$ and $\bar{5}_L$ are different from each other at the unification scale, the R-parity violation effects at a low energy scale appear only through the $\bar{5}'_L \leftrightarrow \bar{5}_L$ mixings. In order to make this R-parity violation effect harmless for proton decay, a discrete symmetry Z_3 and a triplet-doublet splitting mechanism analogous to the Higgs sector are assumed.

1 Introduction

Why do the neutrinos have such tiny masses? There are typical two ideas of the origin of neutrino masses: One is the so-called "seesaw mechanism[1], and the other one is the "radiative mass-generation mechanism[2]. The former can be embedded into a grand unification theory (GUT), but the latter is hard to be embedded into GUT. For example, a supersymmetric (SUSY) model with R-parity violation can provide radiative neutrino masses[3], but the model inevitably induces unwelcome proton decay[4]. Therefore, as an origin of the neutrino masses, the idea of the seesaw mechanism is currently influential concerned with a GUT model. However, the unified description of quark and lepton mass matrices based on a GUT model is not still achieved even if we take the former standpoint. In the present talk, against the current opinion, I would like to investigate another possibility that the neutrino masses are radiatively generated.

The basic idea [5,6] is as follows: We introduce matter fields $\bar{5}'_L + 5'_L$ in addition to the matter and Higgs fields $\bar{5}_L + 10_L + \bar{H}_d + H_u$ in the conventional minimal SUSY SU(5) GUT model. The model has Yukawa interactions $\bar{H}_d\bar{5}_L 10_L$ and R-parity violation-terms $\bar{5}'_L\bar{5}'_L 10_L$. Since the two $\bar{5}$-plet fields, $\bar{5}_L$ and $\bar{5}_L$, in the Yukawa interactions and R-parity violating terms, respectively, are different from each other, the R-parity violation-terms become visible only through $\bar{5}_L \leftrightarrow \bar{5}'_L$ mixing. In order to make the R-parity violation harmless for proton decay, we will assume a mechanism analogous to a triplet-doublet splitting in the Higgs sector.

The explicit model is as follows: We introduce a discrete symmetry Z_3 and assign the Z_3 quantum numbers as follows:

$$\bar{H}_{d(-)} + H_{u(+)} + (\bar{5}_L + 10_L)_{(+)} + (\bar{5}'_L + 5'_L)_{(0)}, \tag{1}$$

where $(+, 0, -)$ denote the Z_3 transformation properties $(\omega^{+1}, \omega^0, \omega^{-1})$ $(\omega = e^{i2\pi/3})$. The Z_3 invariant tri-linear terms are only three:

$$\begin{aligned} W_{tri} = &(Y_u)_{ij} H_{u(+)} 10_{L(+)i} 10_{L(+)j} \\ &+ (Y_d)_{ij} \bar{H}_{d(-)} \bar{5}'_{L(0)i} 10_{L(+)j} \\ &+ \lambda_{ijk} \bar{5}_{L(+)i} \bar{5}_{L(+)j} 10_{L(+)k}. \end{aligned} \tag{2}$$

Note that $\bar{5}'_L$ in the Yukawa interactions are different from $\bar{5}_L$ in the R-parity violation-terms. On the other hand, the Z_3 invariant bi-linear terms are only two. In order to give "triplet-doublet splitting", we assume the following "effective" bi-linear terms:

$$W_{bi} = \bar{H}_{d(-)}(\mu + g_H \langle \Phi_{(0)} \rangle) H_{u(+)}$$

$$+\,\bar{5}'_{L(0)i}(M_5 - g_5\langle\Phi_{(0)}\rangle)5'_{L(0)i}, \quad (3)$$

where Φ is a 24-plet Higgs field and its vacuum expectation value (VEV) is $\langle\Phi\rangle = v_{24}\mathrm{diag}(2,\ 2,\ 2,\ -3,\ -3)$. And we also assume a Z_3 symmetry breaking term

$$W_{SB} = M_i^{SB}\, \bar{\mathbf{5}}_{\mathbf{L}(+)\mathbf{i}} 5'_{L(0)i}, \quad (4)$$

which induces $\bar{5}_L \leftrightarrow \bar{5}'_L$ mixing as follows:

$$\bar{5}'_{L(0)i} = c_i \bar{5}^{q\ell}_{Li} + s_i \bar{5}^{heavy}_{Li},$$

$$\bar{5}_{L(+)i} = -s_i \bar{5}^{q\ell}_{Li} + c_i \bar{5}^{heavy}_{Li}, \quad (5)$$

where

$$s_i^{(a)} = \frac{M^{(a)}}{\sqrt{(M^{(a)})^2 + (M_i^{SB})^2}},$$

$$c_i^{(a)} = \frac{M_i^{SB}}{\sqrt{(M^{(a)})^2 + (M_i^{SB})^2}}, \quad (6)$$

$M^{(2)} = M_5 + 3g_5 v_{24}$, and $M^{(3)} = M_5 - 2g_5 v_{24}$. Therefore, we obtain the following effective R-parity violation-terms:

$$W^{eff}_{\not{R}} = s_i^{(a)} s_j^{(b)} \lambda_{ijk} \bar{5}^{ql(a)}_{Li} \bar{5}^{ql(b)}_{Lj} 10_{Lk}, \quad (7)$$

Hereafter, for simplicity, we denote $\bar{5}^{ql(a)}_{Li}$ as $\bar{5}^{(a)}_{Li}$.

We take the parameter values as follows:

$$M^{(2)} \sim M_{GUT}, \quad M^{(3)} \sim m_{SUSY},$$

$$M_i^{SB} \sim M_{GUT} \times 10^{-1}, \quad (8)$$

so that we obtain values of the mixing parameters $s_i^{(2)} \simeq 1$ and, $c_i^{(2)} \simeq M_i^{SB}/M^{(2)} \sim 10^{-1}$ for the doublet components, and $s_i^{(3)} \simeq M^{(3)}/M_i^{SB} \sim 10^{-12}$ and $c_i^{(3)} \simeq 1$ for the triplet components. Since the unwelcome R-parity violation-terms $d_R^c d_R^c u_R^c$ and $d_R^c(e_L u_L - \nu_L d_L)$ are suppressed by the factors $s^{(3)}s^{(3)} \sim 10^{-24}$ and $s^{(3)}s^{(2)} \sim 10^{-12}$, respectively, the proton decay due to the R-parity violation-terms is suppressed by the factor of 10^{-36}. On the other hand, the R-parity violation-terms $(e_L\nu_L - \nu_L e_L)e_R^c$ are of the order of $s^{(2)}s^{(2)} \sim 1$.

Note that $M_d \neq M_e^T$ in the present model, because

$$M_d^\dagger = C^{(3)} Y_d v_d\ , \quad M_e^* = C^{(2)} Y_d v_d, \quad (9)$$

where $C^{(3)} = \mathbf{1} + O(10^{-24})$ and $C^{(2)} \sim 10^{-1}$.

2 Neutrino mass matrix

First, we calculate a radiative mass from the diagram Fig.1:

$$(M_{rad})_{ij} \propto s_i s_j s_k s_n \lambda^*_{ikm} \lambda^*_{jnl} (M_e)^*_{kl} (\widetilde{M}^{2T}_{eLR})^*_{mn} + (i \leftrightarrow j), \quad (10)$$

where $s_i = s_i^{(2)}$.

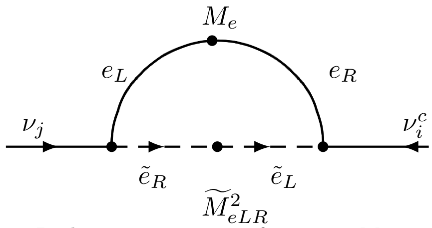

Figure 1. Radiative generation of neutrino Majorana mass

When we define

$$K = (S M_e L^T)^*\ , \quad (11)$$

$$\lambda_{ijk} = \varepsilon_{ijl} L_{lk}\ , \quad (12)$$

$$S = \mathrm{diag}(s_1^{(2)}, s_2^{(2)}, s_3^{(2)}) \simeq \mathbf{1}\ , \quad (13)$$

we can express M_{rad} as

$$(M_{rad})_{ij} = m_0^{-1} s_i s_j \varepsilon_{ikm} \varepsilon_{jln} K_{ml} K_{nk}, \quad (14)$$

where

$$m_0^{-1} = \frac{2}{16\pi^2}(A + \mu^{(2)}\tan\beta)\frac{\ln(m^2_{\tilde{e}_R}/m^2_{\tilde{e}_L})}{m^2_{\tilde{e}_R} - m^2_{\tilde{e}_L}}. \quad (15)$$

Next, we calculate contributions from the non-vanishing sneutrino VEV $\langle\widetilde{\nu}\rangle \neq 0$. In the present model, the VEV of sneutrino is exactly zero at tree level, because of the Z_3 symmetry. However, only an effective m^2_{HLi}-term can appear via the loop diagram $\overline{H}_d \to (\bar{5}^{ql}_L)^c + (10_L)^c \to \bar{5}^{ql}_L$ (Fig. 2), which gives

$$(m^2_{HL_i})_{eff} \propto s_i s_j \lambda_{ijk} (M_e)_{jk} = s_i \varepsilon_{ijk} K^*_{jk}\ . \quad (16)$$

Since $\langle\widetilde{\nu}_i\rangle \propto (m^2_{HL_i})^*_{eff}$, we obtain

$$(M_{VEV})_{ij} = \xi m_0^{-1} s_i s_j \varepsilon_{ikl} \varepsilon_{jmn} K_{kl} K_{mn}, \quad (17)$$

where ξ is a relative ratio of M_{VEV} to M_{rad}.

In conclusion, we obtain the following general form of the neutrino mass matrix[6]

$$(M_\nu)_{ij} = m_0^{-1} s_i s_j \varepsilon_{ikl}\varepsilon_{jmn} \left(K_{kn}K_{ml} + \xi K_{kl}K_{mn}\right), \quad (18)$$

i.e.

$$M_\nu = m_0^{-1} S\left[A(1+\xi)+B\right]S \quad (19)$$

where

$$A = (K-K^T)(K-K^T) - \mathbf{1}\mathrm{Tr}(KK-KK^T),$$
$$B = \left(K+K^T-\mathbf{1}\mathrm{Tr}K\right)\mathrm{Tr}K - (KK+K^TK^T) + \mathbf{1}\mathrm{Tr}(KK), \quad (20)$$

Note that A is a rank-1 matrix which is independent of the diagonal elements of K, K_{11}, K_{22} and K_{33}.

3 A simple example

Hereafter, we discuss the quantities on the flavor basis where M_e is diagonal.

Let us consider a simple form of K which gives $A \gg B$. We assume the following form of K:

$$K/m_{0K} = \begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \varepsilon\mathbf{1}, \quad (21)$$

where m_{0K} is a constant with a dimension of mass. The form (21) means that in the limit of $\varepsilon = 0$, the coefficients λ_{ijk} of the R-parity violation terms are given by $\lambda_{ij1} = \mathrm{const} \equiv \lambda$ and $\lambda_{ij2} = \lambda_{ij3} = 0$, i.e. $\overline{5}_{Li}\overline{5}_{Lj}$ (i.e. $\ell_{Li}\ell_{Lj}$) can couple only to 10_{L1} (i.e. e^c_R). The assumption (21) leads to

$$M_\nu = (1+\xi)A + B, \quad (22)$$

where

$$A = m_{0K}^2 \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \end{pmatrix}, \quad (23)$$

and

$$B = m_{0K}^2\varepsilon \begin{pmatrix} 2\varepsilon & 1 & 1 \\ 1 & -(1+\varepsilon) & 0 \\ 1 & 0 & -(1+\varepsilon) \end{pmatrix}, \quad (24)$$

$m_0^\nu = m_0^{-1} m_{0K}^2$ and we have put $S = \mathbf{1}$. The mass matrix (22) gives the following eigenvalues and mixings:

$$\begin{aligned} m_{\nu 1} &= (\sqrt{3}-1-2\varepsilon)\varepsilon m_0^\nu , \\ m_{\nu 2} &= -(\sqrt{3}+1+2\varepsilon)\varepsilon m_0^\nu , \\ m_{\nu 3} &= 2(1+\xi-\varepsilon-\varepsilon^2) m_0^\nu , \end{aligned} \quad (25)$$

$$U_\nu = \begin{pmatrix} \sqrt{\frac{\sqrt{3}+1}{2\sqrt{3}}} & -\sqrt{\frac{\sqrt{3}-1}{2\sqrt{3}}} & 0 \\ \frac{1}{\sqrt{6+2\sqrt{3}}} & \frac{1}{\sqrt{6-2\sqrt{3}}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6+2\sqrt{3}}} & \frac{1}{\sqrt{6-2\sqrt{3}}} & \frac{1}{\sqrt{2}} \end{pmatrix}. \quad (26)$$

Note that the structure of the mixing matrix U_ν, (26), is independent of the parameters ξ and ε. Therefore, we obtain the neutrino mixing parameters

$$\tan^2\theta_{solar} = \frac{\sqrt{3}-1}{\sqrt{3}+1} = 0.268, \quad (27)$$

together with $\sin^2 2\theta_{atm} = 1$ and $|U_{13}|^2 = 0$, and the ratio of the neutrino mass squared

$$R \equiv \frac{\Delta m_{21}^2}{\Delta m_{32}^2} \simeq \frac{\sqrt{3}(1+2\varepsilon)}{(1+\xi)(1+\xi-2\varepsilon)}\varepsilon^2. \quad (28)$$

Roughly speaking, the these results are favorable to the recent neutrino data [7,8]. Although the predicted value of $\tan^2\theta_{solar}$ is somewhat smaller than the observed best fit value, the value can suitably be adjusted by a small deviation of S from $S = \mathbf{1}$ and the renormalization group equation effects.

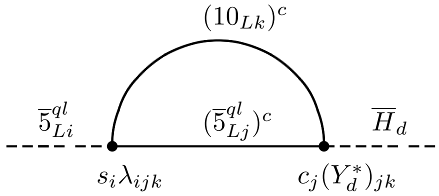

Figure 2. Effective $\overline{5}^{ql}_L\overline{H}^\dagger_d$ term

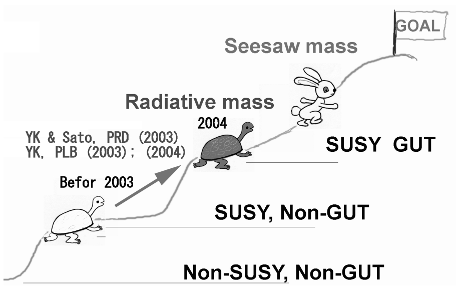

Figure 3. The status of the origin of the neutrino mass in 2004: the radiative neutrino mass hypothesis has considerably become plausible than before

4 Conclusions

Based on a SUSY SU(5) GUT model with harmless R-parity violation, we have proposed a neutrino mass matrix with a simple form, which are given by sum of the radiative masses plus nonvanishing sneutrino VEV contributions. The model with a simple assumption (21) leads to reasonable results

$$\sin^2 2\theta_{23} = 1, \quad |U_{13}| = 0,$$
$$\tan^2 \theta_{12} = \frac{\sqrt{3}-1}{\sqrt{3}+1} = 0.268, \qquad (29)$$

independently of the parameters ε and ξ. However, at present, it is an open question why we should choose such the simple form of K.

Although the form (21) is only an example, we can, at least, say that, as the origin of the neutrino masses, we should seriously take a possibility of the radiative mass generation mechanism as well as that of the seesaw mechanism.

Acknowledgments

This work was supported by the Grant-in-Aid for Scientific Research, the Ministry of Education, Science and Culture (Grant Number 15540283).

References

1. T. Yanagida, in Proceedings of the Workshop on the Unified Theory and Baryon Number in the Universe, edited by O. Sawada and A. Sugamoto (KEK, Tsukuba, 1979), p. 95; M. Gell-Mann, P. Ramond and R. Slansky, in Supergravity, edited by P. van Nieuwenhuizen and D. Freedman (North-Holland, Amsterdam,1979), p. 315; G. Senjanović and R. N. Mohapatra, Phys. Rev. Lett. **44**, 912 (1980).
2. A. Zee, Phys. Lett. **93B**, 389 (1980); **161B**, 141 (1985); L. Wolfenstein, Nucl. Phys. **B175**, 93 (1980); S. T. Petcov, Phys. Lett. **115B**, 401 (1982).
3. L. J. Hall and M. Suzuki, Nucl. Phys. **B231**, 419 (1984); M. Drees, S. Pakvasa, X. Tata and T. ter Veldhuis, Phys. Rev. **D57**, 5335 (1998); G. Bhattacharyya, H. V. Klapdor-Kleingrothaus and H. Pas, Phys. Lett. **B463**, 77 (1999); K. Cheung and O. C. W. Kong, Phys. Rev. **D61**, 113012 (2000).
4. A. Yu. Smirnov and F. Vissani, Nucl. Phys. **B460**, 37 (1996); A. Yu. Smirnov and F. Vissani, Phys. Lett. **B380**, 317 (1996).
5. Y. Koide, Phys. Lett. **B574**, 82 (2003), hep-ph/0308097.
6. Y. Koide, Phys. Lett. **B595**, 469 (2004), hep-ph/0403077.
7. C. McGrew, ICHEP 2004.
8. Y. Wang, ICHEP 2004.