R-Parity Violation in a SUSY GUT Model and Radiative Neutrino Masses*

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1. Introduction

The origin of the neutrino mass generation is still a mysterious problem in the unified understanding of the quarks and leptons. Although the idea of the so-call seesaw mechanism is currently influential, an alternative idea that the neutrino masses are radiatively induced is also attractive. For example, we can consider a SUSY model with R-parity violation. However, usually, it is accepted that SUSY models with R-parity violation are incompatible with a GUT scenario, because the R-parity-violating interactions induce unwelcome proton decay. We wish to build a model which leads to a suppression of the R-parity violating terms with baryon number violation, but to a visible contribution for lepton number violating terms.

The basic idea is as follows [1]: there are no R-parity violating terms $\overline{5}_L\overline{5}_L 10_L$ in the original superpotential. The terms are exactly forbidden by a discrete symmetry Z_2. However, below $\mu < M_X$ (M_X is a unification scale of the SU(5) GUT), the Z_2 symmetry is softly broken, and $\overline{H}_d \leftrightarrow \overline{5}_L$ mixing is induced, so that the R-parity violation terms $\overline{5}_L\overline{5}_L 10_L$ are effectively induced from the Yukawa interactions $\overline{H}_d\overline{5}_L 10_L$. Influenced by a triplet-doublet splitting mechanism of the 5-plet Higgs fields (we denote the triplet and doublet components of the Higgs fields H as $H^{(3)}$ and $H^{(2)}$, respectively, the mixing $\overline{H}_d^{(3)} \leftrightarrow \overline{5}_L^{(3)}$ is highly suppressed, while the mixing $\overline{H}_d^{(2)} \leftrightarrow \overline{5}_L^{(2)}$ is kept visibly. It is worthwhile noting that the coefficients of $\overline{5}_L\overline{5}_L 10_L$ in the present model are proportional to the down-quark and charged lepton mass matrices, M_d and M_e.

2. Model

We consider matter fields $\overline{5}_{L(+)} + 10_{L(-)}$ and two types of 5-plet and $\overline{5}$-plet Higgs fields $H_{(\pm)}$ and $\overline{H}_{(\pm)}$, where $(\pm)$ denote the transformation properties under a discrete symmetry Z_2. The superpotential in the present model is given by

$$W = W_Y + W_H + W_{mix} \ , \qquad (2.1)$$

$$W_Y = \sum_{i,j} (Y_u)_{ij} H_{(+)} 10_{L(-)i} 10_{L(-)j} + \sum_{i,j} (Y_d)_{ij} \overline{H}_{(-)} \overline{5}_{L(+)i} 10_{L(-)j} \ , \qquad (2.2)$$

$$W_H = \overline{H}_{(+)}(m_+ + g_+\Phi)H_{(+)} + \overline{H}_{(-)}(m_- + g_-\Phi)H_{(-)} + m_{SB}\overline{H}_{(+)}H_{(-)} \ , \qquad (2.3)$$

$$W_{mix} = m_5 c_i \overline{5}_{L(+)i} H_{(+)} \ , \qquad (2.4)$$

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where Φ is a 24-plet Higgs field with the vacuum expectation value (VEV) $\langle\Phi\rangle = v_{24}\mathrm{diag}(2,2,2,-3,-3)$, and it has been introduced in order to give doublet–triplet splittings in the SU(5) 5- and $\overline{5}$-plets Higgs fields at an energy scale $\mu < M_X$. The Z_2 symmetry is violated only by the term $\overline{H}_{(+)}H_{(-)}$. Note that $\overline{H}_{(+)}$ and $H_{(-)}$ in the m_{SB}-term do not contribute to the Yukawa interaction (2.2) directly.

The mass matrix in the basis of $(\overline{H}^{(a)}_{(-)}, \overline{H}^{(a)}_{(+)}, \overline{5}^{(a)}_{L(+)1})$ and $(H^{(a)}_{(+)}, H^{(a)}_{(-)})$ is given by

$$M = \begin{pmatrix} 0 & m_-^{(a)} \\ m_+^{(a)}\cos\alpha^{(a)} & m_{SB} \\ m_+^{(a)}\sin\alpha^{(a)} & 0 \end{pmatrix} , \qquad (2.5)$$

where $a = 2,3$, $\overline{5}_{L(+)1} = \sum_i c_i \overline{5}_{L(+)i}$ $(\sum_i |c_i|^2 = 1)$, and $m_+^{(2)}\cos\alpha^{(2)} = m_+ - 3g_+v_{24}$, $m_-^{(2)}\sin\alpha^{(2)} = m_- - 3g_-v_{24}$, and so on. We will take those parameters as

$$\begin{array}{ll} m_+^{(2)} \sim M_W, & m_+^{(3)} \sim M_X, \\ m_-^{(2)} \sim M_X \times 10^{-1}, & m_-^{(3)} \sim M_X, \\ \tan\alpha^{(2)} \sim \frac{m_5}{M_W}, & \tan\alpha^{(3)} \sim \frac{m_5}{M_X}. \end{array} \qquad (2.6)$$

The mass matrix (2.5) is diagonalized as

$$\overline{U}^\dagger M U = D \equiv \begin{pmatrix} m_1 & 0 \\ 0 & m_2 \\ 0 & 0 \end{pmatrix} , \qquad (2.7)$$

where we have dropped the index (a). Then, the quark and charged lepton mass matrices are given by

$$(M_u)_{ij} = U_{11}^{(2)} (Y_u)_{ij}\, v_u , \qquad (2.8)$$

$$(M_e^*)_{1j} = (\overline{U}_{11}^{(2)}\overline{U}_{33}^{(2)} - \overline{U}_{13}^{(2)}\overline{U}_{31}^{(2)})(Y_d)_{1j}\, v_d, \qquad (2.9)$$

$$(M_d^\dagger)_{1j} = (\overline{U}_{11}^{(2)}\overline{U}_{33}^{(3)} - \overline{U}_{13}^{(3)}\overline{U}_{31}^{(2)})(Y_d)_{1j}\, v_d, \qquad (2.10)$$

and so on. Note that $M_d \neq M_e^T$.

The coefficients of the effective $\not{R}$ terms $\lambda_{1ij}^{(2,2)}(\nu_{L1}e_{Li} - e_{L1}\nu_{Li})e_{Rj}^c + \lambda_{1ij}^{(2,3)}(\nu_{L1}d_{Ri}^c d_{Lj} - e_{L1}d_{Ri}^c u_{Li}) + \lambda_{11j}^{(3,2)}(d_{R1}^c e_{Li}u_{Li} - d_{R1}^c \nu_{Li}d_{Lj}) + \lambda_{1ij}^{(3,3)} d_{R1}^c d_{Ri}^c d_{Rj}^c$ are given by

$$\lambda_{1ij}^{(2,2)} = (1-\delta_{i1})\kappa(M_e^*)_{ij}v_d \qquad (2.11)$$

$$\lambda_{1ij}^{(2,3)} \simeq \kappa(M_d^\dagger)_{ij}/v_d , \qquad (2.12)$$

$$\lambda_{1ij}^{(3,2)} = \xi\kappa(M_e^*)_{ij}/v_d , \qquad (2.13)$$

$$\lambda_{1ij}^{(3,3)} \simeq (1-\delta_{i1})\xi\kappa(M_d^\dagger)_{ij}/v_d , \qquad (2.14)$$

where $\kappa = \overline{U}_{13}^{(2)}/\overline{U}_{11}^{(2)}$ and $\xi = \overline{U}_{13}^{(3)}/\overline{U}_{13}^{(2)}$. Unwelcome terms are highly suppressed by the factor $\xi \sim 10^{-17}$.

3. Neutrino mass matrix

Neutrino mass matrix M_ν is given by sum of the radiative neutrino masses M_ν^{rad} and the contributions $M_{\tilde{\nu}}$ due to the non-zero sneutrino VEV: $M_\nu = M_\nu^{rad} + M_{\tilde{\nu}}$;

$$M_\nu^{rad} = m_0 \left(PSP + kU_R^d P (U_R^d)^\dagger S (U_R^d)^* P (U_R^d)^T \right) , \qquad (3.1)$$

on the basis with $M_e = D_e \equiv \mathrm{diag}(m_e, m_\mu, m_\tau)$, where $P = \mathrm{diag}(1,1,0)$ and S is a rank one matrix which is related with the $\overline{5}_{Li}$-$\overline{H}_d$ mixings. For $M_{\tilde{\nu}}$, we can assume $M_{\tilde{\nu}} \propto S$. A simple example of the form of S which gives successful predictions of the neutrino phenomenology has been given in Ref. [1].

[1] Y. Koide and J. Sato, hep-ph/0305291, to be published in Phys. Rev. **D68**, 0560xx (2003), and references therein.