Neutrino anomalies in a gauge mediated model with trilinear $R$ violation

Anjan S. Joshipura and Rishikesh D. Vaidya

Theoretical Physics Group, Physical Research Laboratory, Navrangpura, Ahmedabad 380 009, India

Sudhir K. Vempati

Department of Theoretical Physics, Tata Institute of Fundamental Research, Colaba, Mumbai 400 005, India

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The structure of neutrino masses and mixing resulting from trilinear $R$ violating interactions is studied in the presence of gauge mediated supersymmetry breaking. Neutrino masses arise in this model at the tree level through the renormalization-group-induced vacuum expectation values of the sneutrinos and also through direct contribution at one loop. The relative importance of these contributions is determined by the values of the strong- and weak-coupling constants. In the case of purely $\lambda^c$ couplings, the tree contribution dominates over the one-loop diagram. In this case, one simultaneously obtains atmospheric neutrino oscillations and quasivacuum oscillations of the solar neutrinos if all the $\lambda^c$ couplings are assumed to be of similar magnitudes. If $R$ parity violation arises from the trilinear $\lambda$ couplings, then the loop-induced contribution dominates over the tree level. One cannot simultaneously explain the solar and atmospheric deficit in this case if all the $\lambda$ couplings are of similar magnitude. This, however, becomes possible with hierarchical $\lambda$ and we give a specific example of this.

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I. INTRODUCTION

A variety of observations of the solar and atmospheric neutrinos have given important information on the possible structures of neutrino masses and mixings. Based on these observations, one can infer that oscillations among three active neutrinos are likely to be responsible for the observed features of the data. These oscillations are characterized by two widely separated mass scales. At least one mixing angle involved in oscillations of atmospheric neutrinos is large [1]. The detailed data on the day-night asymmetry and recoil energy spectrum of the solar neutrinos seem to favor the presence of one more large mixing angle [2]. Thus the neutrino mass spectrum seems to be characterized by hierarchical (mass)$^2$ differences and by two large and one small mixing angle, with the small mixing angle demanded by the CHOOZ experiment [3]. Many mechanisms have been advanced to understand these features of the neutrino spectrum [4]. One of these is provided by supersymmetric theory, which contains several features to make it attractive for the description of the neutrino spectrum. The lepton number violation needed to understand neutrino masses is built into this theory through the presence of the $R$ parity violating couplings [5]. Moreover, it is possible to understand the hierarchical neutrino masses and large mixing among them within this framework without fine-tuning of parameters or without postulating ad hoc textures for the neutrino mass matrices [6,7].

The supersymmetrized version of the standard model contains the following lepton number-violating couplings:

$$W_i = \epsilon_i L_i H^*_2 + \lambda_{ijk} L_i L_j e^c_k + \lambda'_{ijk} L_i Q_j d^c_k,$$

where $L, Q, H^*_2$ represent the lepton, quark, and one of the Higgs doublets (up-type), respectively, and $e^c, d^c$ represent the leptonic down quark singlets. Each of these couplings is a potential source for neutrino masses. There have been detailed studies of the effects of these couplings on neutrino masses under different assumptions [6–11]. We briefly recapitulate the relevant gross features of these studies and motivate additional work that we are going to present in this paper.

The most studied effect is that of the three bilinear mass parameters $\epsilon_i$, particularly in the context of supersymmetry breaking with universal boundary conditions at a high scale [6–8,10,11]. This formalism provides a nice way of understanding suppression in the neutrino mass $m_\nu$ compared to the weak scale. The mixing among neutrinos is largely controlled in this approach by the ratios of the parameters, $\epsilon_i$. This can be approximately described by the following matrix for a large range in parameter space of the minimal supersymmetric standard model with radiative $SU(2) \times U(1)$ breaking [6,7,11]:

$$U = \begin{pmatrix} c_1 & s_1 c_2 & s_1 s_2 \\ -s_1 & c_1 c_2 & c_1 s_2 \\ 0 & -s_2 & c_2 \end{pmatrix},$$

where

$$s_1 = \frac{\epsilon_1}{\sqrt{\epsilon_1^2 + \epsilon_2^2}}, \quad s_2 = \frac{\sqrt{\epsilon_1^2 + \epsilon_2^2}}{\epsilon_1 + \epsilon_2 + \epsilon_3}.$$  

The above matrix can reproduce nicely the small angle Mikheyev-Smirnov-Wolfenstein (MSW) solution together with the atmospheric neutrino anomaly. However, because of the specific structure, one cannot have two large mixing angles keeping at the same time $|U_{e3}| \leq 0.1$ as required from the negative results of CHOOZ. Thus purely bilinear $R$ violation with universal boundary conditions cannot account for the observed features with two large mixing angles. This