Adulteraded Dirac neutrinos in a type-I seesaw

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Abstract

Recently we proposed a type-I seesaw with two right-handed (RH) neutrinos per generation naturally leading to light Dirac neutrinos. These have an adulterated nature as their ordinary RH components are integrated out and replaced by the extra ones of much weaker couplings. The great disparity between their couplings is guaranteed by an underlying electroweak symmetry defined with one RH neutrino by transformations exchanging lepton and quark bare states with equal charges. Here we briefly review our findings.

1. Introduction

- The Dirac nature of light neutrinos remains a possibility which has not been so much studied.
- Their tiny masses can be explained by the type-I seesaw with extra RH neutrinos having quite different mass terms, undertaken by the pre-symmetry with one RH neutrino.

2. Seesaw with two RH neutrinos

In the approximation of one generation, the mass matrix of

$$-\mathcal{L}_\nu = \frac{1}{2}(\bar{\nu}_L \quad \bar{\nu}_L^c \quad \bar{\nu}_L'^c)\begin{pmatrix} 0 & m_D & m'_D \\ m_D & m_R & \mu' \\ m'_D & \mu' & m'_R \end{pmatrix}\begin{pmatrix} \nu_R^c \\ \nu_R \\ \nu'_R \end{pmatrix} + h.c.$$

with $m'_R, \frac{m_D^2}{m_R}, \frac{\mu' m_D}{m_R}, \frac{\mu'^2}{m_R} \ll m'_D \ll m_D \ll m_R$

has the mass eigenvalues

$$m_1 \simeq -m'_D + \frac{1}{2}m'_R - \frac{1}{2}\frac{(m_D - \mu')^2}{m_R} \simeq -m'_D \; ; \; m_2 \simeq m_R$$

$$m_3 \simeq m'_D + \frac{1}{2}m'_R - \frac{1}{2}\frac{(m_D + \mu')^2}{m_R} \simeq m'_D$$

for the three Majorana states $\nu_{iM} = \nu_{iL} + \nu_{iR}^c$, ν_R being decoupled and **ν_L mixing with ν'_R maximally.**

3. Adulterated Dirac neutrinos

Integrating ν_R out, the effective Lagrangian is

$$-\mathcal{L}_\nu = \frac{1}{2}(\bar{\nu}_L \quad \bar{\nu}_L'^c)\begin{pmatrix} m_{LL} & m'_{LR} \\ m'_{LR} & m'_{RR} \end{pmatrix}\begin{pmatrix} \nu_R^c \\ \nu'_R \end{pmatrix} + h.c.$$

where

$$m_{LL} \simeq -\frac{m_D^2}{m_R} \ll m'_D$$

$$m'_{RR} \simeq m'_R - \frac{\mu'^2}{m_R} \ll m'_D$$

$$m'_{LR} \simeq m'_D - \frac{\mu' m_D}{m_R} \simeq m'_D$$

Dirac neutrinos with small masses can be accommodated naturally, but with **the extra ν'_R taking the place of the ordinary ν_R.** Lepton-quark symmetry is restored with adulterated neutrinos.

4. Presymmetry with one RH neutrino

This electroweak symmetry substantiates the hierarchy of masses, based on the lepton-quark hypercharge relations

$$Y(\nu_L) = Y(u_L) + \Delta Y(u_L) = -1$$

$$Y(\nu_R) = Y(u_R) + \Delta Y(u_R) = 0$$

$$Y(e_L) = Y(d_L) + \Delta Y(d_L) = -1$$

$$Y(e_R) = Y(d_R) + \Delta Y(d_R) = -2$$

where $\Delta Y = 4(L - 3B)/3$.

A dequantization is suggested, understood in terms of bare states of leptons **(pre-leptons)** with fractional charges.

They are defined by

$$Y(\hat{\nu}_{L,R}) = Y(u_{L,R}) \; ; \; \Delta Y(\hat{\nu}_{L,R}) = \Delta Y(u_{L,R})$$

$$Y(\hat{e}_{L,R}) = Y(d_{L,R}) \; ; \; \Delta Y(\hat{e}_{L,R}) = \Delta Y(d_{L,R})$$

where $\Delta Y = 4(3L - B)/3$. Essentially, $\Delta Y = n/3$, with $n = -4$ as the topological charge required to cancel anomalies. Presymmetry is the invariance under the transformations $\hat{\nu}_{L,R} \leftrightarrow u_{L,R}$, $\hat{e}_{L,R} \leftrightarrow d_{L,R}$.

The second RH neutrino breaks this symmetry, providing the seed for Dirac neutrinos with small masses.

5. Phenomenological remarks

- The indicative values for the parameters are

$$m_R \geq \mathcal{O}(10^{12} GeV) \; ; \; m_D = \mathcal{O}(1\ MeV) \; ; \; m'_D = \mathcal{O}(10^{-1} eV)$$

$$m'_R \leq \mathcal{O}(10^{-9} eV) \; ; \; \mu' \leq \mathcal{O}(1\ MeV)$$

- The model can be tested through the successes of the standard model and the Dirac nature of light neutrinos.

6. Conclusions

- The type-I seesaw with a second family of RH neutrinos implemented with presymmetry can be the source for light Dirac neutrinos.
- Although there are no hard predictions for their masses and couplings, this model provides a new line of neutrino physics for exploration.

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