# LIGHT DIRAC NEUTRINOS AND MIRROR FERMIONS

Sudhakar PANDA
*Institute of Physics, Bhubaneswar-751005, India* [1]
*and Physics Department, North Bengal University, Darjeeling-734430, India*

and

Utpal SARKAR
*Physics Department, Calcutta University, 92, A.P.C. Road, Calcutta-700009, India*
*and Physics Department, North Bengal University, Darjeeling-734430, India*

Received 30 January 1984

It is pointed out that any left–right symmetric theory containing mirror fermions can accommodate a light Dirac neutrino in a natural way.

The problem of neutrino mass has recently been reviewed, following two recent experiments. The recent ITEP experiment [1] has set a lower bound on the mass of the neutrino $m(\bar{\nu}_e) > 20$ eV, while the lack of observable neutrinoless nuclear double beta-decay [2] has yielded an upper limit of 10 eV for the Majorana mass of the neutrino. An interface of the above two results and an older upper limit [3] of 55 eV for neutrino mass is that the neutrino has a Dirac mass somewhere between 20 eV and 55 eV.

It is now believed that an explanation of the above result is beyond the scope of the conventional unified gauge theories. Recently, attempts have been made to incorporate light Dirac neutrinos in a supergrand unification theory [4], where the standard SUSY SO(10) GUT has been extended to include one gauge singlet scalar field and two gauge singlet left-handed fermion fields. No such additional fields are required in a more recent work [5], where the same scheme (proposed in ref. [4]) has been applied to left–right symmetric and to horizontal gauge models with four generations of fermions. The results are, however, inapplicable to models with three generations of fermions. The present work illustrates that any left–right symmetric models, which predict mirror fermions, can accommodate a light Dirac neutrino for each generation.

The idea of mirror fermions [6–9] has been exploited to construct various models. The maximal symmetry of a 16-member two-component fermion family, SU(16) [6], and its family extensions carry an unavoidable prediction that there must exist three families of mirror fermions supplementing the e, $\mu$, $\tau$ families. Unified models of three observed families of fermions with the exceptional group $E_8$ [7] also predict the existence of mirror fermions. Other unified models of three fermion families, where the horizontal gauge group $SU(3)_H^{VL}$ accounts for the generational structure [8], also predict the existence of mirror fermions. Mirror fermions are also predicted by some composite models of quarks and leptons [9].

The mirror fermions have the following characteristics. They couple to the charged gauge particles $W^{\pm}$ generating familiar low energy weak interactions, through V + A rather than V − A currents; their masses lie between 20–200 GeV and their mixing with ordinary fermions, if at all, is very small. To visualise these conclusions, consider the 16 left-handed Weyl spinors of one family ("electronic" multiplet),

[1] Permanent address.

$$F_L^e = \left\{ \begin{pmatrix} u \\ d \end{pmatrix}^{r,y,b} \begin{pmatrix} \nu \\ e^- \end{pmatrix} \middle| \begin{pmatrix} u^c \\ d^c \end{pmatrix}^{r,y,b} \begin{pmatrix} \nu^c \\ e^+ \end{pmatrix} \right\}_L \equiv \{f_L | f_L^c\} . \quad (1)$$

In SU(16) GUT, all these particle states are assigned to a single 16-plet fundamental representation and all the right-handed particles are assigned to an anti-16-plet representation. Such assignment would generate triangle anomalies. Similarly, theories with $SU(3)_H^{VL}$ horizontal gauge symmetries will generate anomalies, since all the left-handed fermions of three generations have been accommodated in 16 $SU(3)_H^{VL}$ triplets with the right-handed particles in 16 antitriplets. For this reason, the above mentioned theories should postulate a mirror set of fermions $F^{me}$, with a helicity flip coupling, supplementing the basic set $F^e$ such that the anomalies of the basic and mirror fermions cancel each other. The mirror right-handed Weyl spinors will be contained in a 16-plet representation of SU(16), or the right-handed mirror particles and mirror antiparticles of three generations will transform as 16 triplets under $SU(3)_H^{VL}$:

$$F_R^{me} = \left\{ \begin{pmatrix} u^m \\ d^m \end{pmatrix}^{r,y,b} \begin{pmatrix} \nu^m \\ e^{m-} \end{pmatrix} \middle| \begin{pmatrix} u^{mc} \\ d^{mc} \end{pmatrix}^{r,y,b} \begin{pmatrix} \nu^{mc} \\ e^{m+} \end{pmatrix} \right\}_R \equiv \{f_R^m | f_R^{mc}\} . \quad (2)$$

The mirror discrete symmetry $F_L^e \leftrightarrow F_R^{me}$ will then make the theory vector-like and *is* anomaly free.

While discussing the fermion masses in these theories, we shall work with the group $G_{PS} = SU(2)_L \otimes SU(2)_R \otimes SU(4)_c$ without loss of generality, since $G_{PS} \subset SU(16)$ and all the three fermion families can be accommodated within $G_{PS} \otimes SU(3)_H^{VL}$ which is again contained in $E_8$. We shall consider a single stage symmetry breaking,

$$G_{PS} \xrightarrow{M_R} SU(2)_L \otimes U(1)_Y \otimes SU(3)_c \xrightarrow{M_L} U(1)_Q \otimes SU(3)_c . \quad (3)$$

The minimal set of Higgs multiplets that are needed by this model are

$$\phi_1 = (2,2,1), \quad \phi_2 = (2,2,1), \quad \Delta_L = (3,1,10), \quad \Delta_R = (1,3,10) . \quad (4)$$

The associated pattern of VEVs, in obvious notation, is

$$\langle (\Delta_{L,R})_{44}^{I_{3L,R}=+1} \rangle = v_{L,R} , \quad \langle \phi_1 \rangle = \begin{pmatrix} k & 0 \\ 0 & k' \end{pmatrix} , \quad \langle \phi_2 \rangle = \begin{pmatrix} \tilde{k} & 0 \\ 0 & \tilde{k}' \end{pmatrix} , \quad (5)$$

$\langle \phi_1 \rangle$ contributes to the mass of the mirror fermions and $\langle \phi_2 \rangle$ to the ordinary fermions. For consistency with phenomenology, one needs the hierarchy

$$\langle \Delta_R \rangle \gg \langle \phi_1 \rangle \gg \langle \phi_2 \rangle \gg \langle \Delta_L \rangle . \quad (6)$$

This result is consistent with the minima of the most general potential of the theory, involving the fields $\Delta_{L,R}$ and $\phi_{1,2}$ [10]. This situation retains the left–right symmetry, discrete mirror symmetry,

$$F_L^e \leftrightarrow F_R^{me} , \quad (7)$$

supplemented by the symmetry

$$\phi_1 \leftrightarrow \phi_2 , \quad (8)$$

in the full basic lagrangian. We shall further impose the condition that the lagrangian is invariant under the transformation

$$F_L^e \leftrightarrow F_L^e , \quad F_R^{me} \leftrightarrow -F_R^{me} , \quad (9)$$

to prevent a mass-mixing between basic and mirror fermions to all orders of perturbation theory. We shall now demonstrate how a little deviation from the conventional theories with mirror fermions can accommodate a light Dirac neutrino in each generation. We impose the condition that under the transformation (9)

$$\Delta_{L,R} \to -\Delta_{L,R} . \quad (10)$$

In absence of this additional symmetry, all the features of conventional GUTs will be restored and neutrinos will have Majorana masses. However, the presence of this additional symmetry will give rise to new interesting physics, which we shall now discuss.

The Yukawa coupling terms in the lagrangian, which will give rise to the masses of the fermions through spontaneous symmetry breaking, are now given by

$$\mathcal{L} = h_1(\bar{f}_L^m f_R^m \phi_1 + \bar{f}_L f_R \phi_2) + \text{h.c.} + h_2(\bar{f}_L^{mc} f_L \Delta_L + \bar{f}_R^{mc} f_R \Delta_R) + \text{h.c.} \quad (11)$$

After the Higgs scalars acquire VEVs [eq. (5)], the above expression will give rise to the following mass matrix for the basic and mirror neutrinos,

$$
\begin{array}{c|cccc}
 & \nu_L^m & \nu_L^c & \nu_L^{mc} & \nu_L \\
\hline
\bar{\nu}_R^{mc} & 0 & 0 & h_1 k & h_2 v_L \\
\bar{\nu}_R & 0 & 0 & h_2 v_R & h_1 \tilde{k} \\
\bar{\nu}_R^m & h_1 k & h_2 v_R & 0 & 0 \\
\bar{\nu}_R^c & h_2 v_L & h_1 \tilde{k} & 0 & 0
\end{array}
\qquad (12)
$$

The four nonzero eigenvalues of (12) split into two pairs, each of which consists of degenerate members (with opposite signs) yielding two Dirac masses ‡1 given by

$$\pm \frac{h_2 v_R}{\sqrt{2}} [1 + c]^{1/2} \times \left\{ 1 \pm \left[ 1 - \left( \frac{2}{h_2^2 v_R^2} \frac{h_1^2 k\tilde{k} - h_2^2 v_L v_R}{1 + c} \right)^2 \right]^{1/2} \right\}^{1/2},$$

with

$$c = (h_1^2 k^2 + h_1^2 \tilde{k}^2 + h_2^2 v_L^2)/h_2^2 v_R^2 . \qquad (13)$$

Using the inequality (6) in expression (13) we obtain the masses of the two Dirac neutrinos to leading order to be

$$h_2 v_R \quad \text{and} \quad (h_2 v_R)^{-1} (h_2^2 v_L v_R - h_1^2 k\tilde{k}) . \qquad (14)$$

A natural choice of the parameters ‡2, involved in expression (14), is

$$v_R \sim M_R \sim 10^9\ \text{GeV}; \quad h_1 k \sim m_e^{\text{mirror}} \sim 10^2\ \text{GeV},$$

$$h_1 \tilde{k} \sim m_e \sim 10^{-3}\ \text{GeV}, \quad v_L \sim (h_1 k)^2 / v_R \sim 10^{-5}\ \text{GeV},$$

$$h_2 \sim 10^{-3}, \quad \text{so,}\ h_2 v_L \sim 10\ \text{eV} . \qquad (15)$$

This will lead to the Dirac masses of the neutrinos to be $10^6$ GeV and 10 eV. This can explain the recent experiments [1–3] satisfactorily.

It is clear from eq. (11) that the $\Delta_{L,R}$ field can only couple with an ordinary fermion and a mirror fermion. Thus, any fermion can go to a mirror antifermion through a Yukawa coupling with $\Delta_{L,R}$. Thus. processes like n–n transition or neutrinoless double beta-decay will be absent in this model. However, n–$n^{\text{mirror}}$ transition is allowed and a ($e^- e^{m-}$) can be found (without any neutrinos) in a collision of a neutron with a mirror neutron [10].

We can summarize our results as follows. A little variation of the left–right symmetric theories with mirror fermions can account for a light Dirac neutrino and hence it can explain the recent experimental results on neutrino mass [1–3]. The present version of the theory does not allow neutrinoless double beta-decay or n–n oscillations. However, neutron ↔ mirror antineutron transition is allowed.

One of the authors (U.S.) thanks P. Mazumdar, S.P. Misra, R.N. Mohapatra, P. Roy and O. Shankar for helpful discussoins. We would like to thank S. Mukherjee for various help. S.P. thanks S.N. Sen and other faculty members of the Physics Department, N.B. University for hospitality and S.P. Misra for constant inspiration. This work was supported by the Indian Space Research Organization.

‡1 Two degenerate Majorana neutrinos can yield a Dirac neutrino naturally in a unified theory, first pointed out in ref. ref. [11].

‡2 The choice of parameters considered here is consistent with the minima of the potential and one loop renormalization group analysis [10].

*References*

[1] S. Boris et al., ITEP report, to be published, quoted by V.A. Lubimov, talk Intern. Conf. on High energy physics (Brighton, UK, 1983);
V.A. Lubimov et al., Phys. Lett. 94B (1980) 266.
[2] F.T. Avignone et al., Phys. Rev. Lett. 50 (1983) 721;
E. Bellotti et al., to be published, quoted by V. Khoransky, talk Intern. Conf. on High energy physics (Brighton, UK, 1983);
T. Kirsten, H. Richter and E. Jessberger, Phys. Rev. Lett. 50 (1983) 474.
[3] K.E. Bergkvist, Nucl. Phys. B39 (1972) 317.
[4] P. Roy and O. Shanker, TIFR preprint TIFR/TH/83-35.
[5] O. Shanker, TIFR preprint TIFR/TH/83-37.
[6] J.C. Pati, A. Salam and J. Strathdee, Phys. Lett. 108B (1982) 121.
[7] I. Bass and M. Gunaydin, Phys. Rev. Lett. 45 (1980) 859;
U. Sarkar, Super GUTs with three fermion families, in preparation.
[8] B.B. Deo and U. Sarkar, ICTP preprint IC/83/102.
[9] R.N. Mohapatra, M. Yasue and O.W. Greenberg, Maryland preprint 220 (1983).
[10] S. Panda, S. Mishra, U. Sarkar and S.P. Misra, in preparation.
[11] L. Wolfenstein, Nucl. Phys. B186 (1981) 147.