Preprint YERPHI-1140(17)-89

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ
ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ
YEREVAN PHYSICS INSTITUTE

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NEUTRINO MASSES IN LEFT-RIGHT SYMMETRIC MODELS

ЦНИИатоминформ
ЕРЕВАН - 1989

Նախնատիպ ԵՖԻ-1140(17)-89

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ՁԱԽ-ԱՋ ՀԱՄԱՉԱՓ ՄՈԴԵԼՆԵՐՈՒՄ ՆԵՅՏՐԻՆՈՅԻ ԶԱՆԳՎԱԾՆԵՐԸ

Դուրս են բերված տեսությունում մեկ կամ երկու $SU(2)_L$ երկյակի առկայության դեպքում ձախ-աջ համաչափ մոդելներում նեյտրինոյի մայորանյան զանգվածի վերաբերյալ ճշտումները: Առաջին դեպքում ճառագայթային ճշտումները զգալի են Հիգսի դաշտի մեծ զանգվածների դեպքում/մի քանի հազար ԳէՎ/: Եթե տեսությունում կա երկրորդ երկյակը $SU(2)_L$ դիրակյան լիցքավորված լեպտոնների զանգվածները ավելի փոքր են դիրակյան նեյտրինոյի զանգվածներից $\left(\frac{m_\ell}{m_\nu^D} \ll 1\right)$, ապա այն լրացուցիչ զգալի ներդրում ունի նեյտրինոյի զանգվածում: Վերջին դեպքում կարող են զգալիորեն տարբերվել ծառերի մոտարկումից ոչ միայն զանգվածները, այլև նեյտրինոյի խառնման անկյունները:

Երևանի Ֆիզիկայի ինստիտուտ

Երևան 1989

Центральный научно-исследовательский институт информации и технико-экономических исследований по атомной науке и технике (ЦНИИатоминформ) 1989 г.

Preprint YERPHI-1140(17)-89

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NEUTRINO MASSES IN LEFT-RIGHT SYMMETRIC MODELS

The radiative corrections to the majorana neutrino mass in the left-right symmetric models are calculated in the presence of one or two $SU(2)_L$ doublets in theory. In the former case the radiative corrections are essential for large (a few hundreds of GeV) masses of Higgs field. If a second $SU(2)_L$ doublet exists in theory, then it makes an additional essential contribution to the neutrino mass provided that the Dirac masses of charged leptons are much less than the Dirac masses of neutrino ($\frac{m_\ell}{m_\nu^0} \ll 1$). In the latter case not only masses but also mixing angles of neutrino may considerably differ from the tree approximation.

Yerevan Physics Institute

Yerevan 1989

Препринт ЕФИ-1140(17)-89

Г.М.АСАТРЯН,А.Н.ИОАННИСЯН

МАССЫ НЕЙТРИНО В ЛЕВО-ПРАВО СИММЕТРИЧНЫХ МОДЕЛЯХ

Вычислены радиационные поправки к майорановской массе нейтрино в лево-право симметричных моделях при наличии в теории одного или двух $SU(2)_L$ дублетов. В первом случае радиационные поправки существенны при больших (несколько сотен ГэВ) массах поля Хиггса. Если в теории существует второй $SU(2)_L$ дублет, то он вносит дополнительный существенный вклад в массу нейтрино, если дираковские массы заряженных лептонов намного меньше дираковских масс нейтрино $\left(\frac{m_e}{m_\nu^2} \ll 1\right)$. В последнем случае могут существенно отличаться от древесного приближения не только массы, но и углы смешивания нейтрино.

Ереванский физический институт
Ереван 1989

The Dirac neutrino masses in the left-right symmetric models are of the same order as the masses of other fermions. In particular, in a simplest version of SO(10) model they are equal to the masses of upper quarks, i.e. they are inadmissibly large. In Ref. 1 Gell-Mann et al. have noted for the first time that in such models at (B-L) symmetry breaking the right component of neutrino acquires majorana mass, owing to which the mass matrix takes a form:

$$\mathcal{M} = \begin{pmatrix} 0 & m^{D} \\ m^{D} & M_R \end{pmatrix} \begin{matrix} \nu_L \\ \nu_R^c \end{matrix} \quad (1)$$
$$\qquad \overline{\nu_L^c} \quad \overline{\nu_R}$$

After diagonalization of this matrix we obtain instead of one Dirac neutrino two majorana neutrinos:

$$\nu_1 = c\cdot\nu_L + s\nu_R^c + c\,\nu_L^c + s\,\nu_R ,$$

$$\nu_2 = -s\cdot\nu_L + c\,\nu_R^c - s\nu_L^c - c\,\nu_R , \quad (2)$$

$$s = \sin\alpha , \quad c = \cos\alpha , \quad tg\,2\alpha = 2\,\frac{m^D}{M_R}$$

with masses $\quad m_1 \simeq -\frac{m^{D^2}}{M_R} ; \quad m_2 \simeq M_R$

If the scale of (B-L) symmetry breaking is sufficiently large ($M_R \gg m^D$), then the left neutrino mass comes out to be sufficiently small.

In a simplest SO(10) model, if mixing is ignored, the light neutrino masses are $m_{\nu_e} \approx \frac{m_u^2}{M_R}$, $m_{\nu_\mu} \approx \frac{m_c^2}{M_R}$, $m_{\nu_\tau} \approx \frac{m_t^2}{M_R}$. Values of these masses do not contradict the cosmological predictions ($\Sigma m_\nu < 65$ eV) if $M_R > 10^{10}$ GeV.

Our purpose is to consider the radiative corrections to the matrix (1).

Radiative corrections to the matrix (1) were considered elsewhere too.

In many works (see, e.g. [2]) the radiative corrections to matrix (1) were considered on the assumption that the additional light particles exist in the low-energy sector of theory. In Ref. [3] the existence of additional discrete symmetry was assumed.

Here we shall study radiative corrections to the neutrino mass matrix (1) assuming no additional particles or symmetries in theory.

Neutrino obtains a Dirac mass in the $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ scheme owing to Yukawa interaction:

$$g \bar{L}_L \varphi L_R , \qquad (3)$$

where

$$L_{L,R} = \begin{pmatrix} \nu \\ e \end{pmatrix}_{L,R} , \quad \varphi = \begin{pmatrix} \xi^0 & \eta^+ \\ \xi^- & -\bar{\eta}^0 \end{pmatrix} , \quad \langle \xi^0 \rangle^2 + \langle \eta^0 \rangle^2 = (246\,\mathrm{GeV})^2 ;$$

After (B-L) symmetry breaking the right neutrino acquires a majorana mass:

$$g_R L_R^T C \Delta_R L_R , \tag{4}$$

where

$$\Delta_R = \begin{pmatrix} \Delta^0 & \frac{1}{\sqrt{2}}\Delta^+ \\ \frac{1}{\sqrt{2}}\Delta^+ & \Delta^{++} \end{pmatrix} \quad \langle \Delta_R^0 \rangle \sim M_R$$

After acquiring vacuum expectation value (v.e.v.) by fields φ and Δ , we obtain a neutrino mass matrix (1).

Radiative corrections to matrix (1) are small, $O(g^2/16\pi^2)$, therefore they are essential only for the zero element of this matrix, i.e. essential may be radiative corrections to the left neutrino mass.

The left neutrino can obtain mass owing to the interaction with the Higgs field left triplet which is absent in our model. But it can be constructed from doublets ($\underline{2} \times \underline{2} = \underline{3} + \underline{1}$). Taking into account the fact that the v.e.v. of the right triplet breaks the (B-L) symmetry, we can write out an effective term whose v.e.v. gives mass to the left neutrino:

$$\varphi(2.2.0) \times \varphi(2.2.0) \times \Delta_R(1\ 3.2) = \Delta_L^{eff}(3.1.2) \times \ldots \tag{5}$$

Here fields are written in the $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ representation.

The diagram which gives mass to the left neutrino is shown in Fig.1.

If field φ is real, $\varphi = \begin{pmatrix} \eta^0 & \eta^+ \\ \eta^- & -\bar{\eta}^0 \end{pmatrix}$, then this diagram can be presented as a sum of two ordinary (without tails) diagrams (Fig.2). In the first diagram we show a usual Salam-Weinberg Higgs boson running along the loop: $H_{SW} = \frac{\eta^0 + \bar{\eta}^0}{\sqrt{2}}$; in the other one - the Goldstone boson: $H_{gold} = \frac{\eta^0 - \bar{\eta}^0}{i\sqrt{2}}$

Here the left neutrino mass is

$$m_L = \frac{g^2}{16\pi^2} \frac{M_R m_H^2}{M_R^2 - m_H^2} \ln \frac{M_R}{m_H}, \tag{6}$$

where m_H is a mass of a usual Salam-Weinberg Higgs boson.

We rewrite (6) as follows:

$$m_L = \frac{m^{\mathcal{D}2}}{M_R} \frac{1}{8\pi^2} \frac{m_H^2}{<\eta>^2} \frac{1}{1 - \frac{m_H^2}{M_R^2}} \ln \frac{M_R}{m_H} \simeq \frac{m^{\mathcal{D}2}}{M_R} \frac{1}{8\pi^2} \frac{m_H^2}{<\eta>^2} \ln \frac{M_R}{m_H}. \tag{7}$$

With account of the radiative correction the light neutrino mass is

$$m_1 = \frac{m^{\circ 2}}{M_R} \left(-1 + \frac{1}{8\pi^2} \frac{m_H^2}{<\eta>^2} \ln \frac{M_R}{m_H}\right). \tag{8}$$

Fig.3 shows a region where depending on the Higgs boson mass m_H and the right neutrino mass the radiative correction to the neutrino mass may be larger than the tree approximation.

For example, at $M_R = 10^{15}$ GeV the radiative correction is larger than the tree approximation if $m_H > 400$ GeV.

The presence of several generations of neutrino does not change the situation. The mass matrix of light neutrino looks as follows:

$$\mathcal{M}_{ij}^{\nu} = \mathcal{M}_{iK}^{\mathcal{D}} (\mathcal{M}_R^{-1})_{K\ell} A_{\ell n} \mathcal{M}_{jn}^{\mathcal{D}}, \tag{9}$$

where

$$A_{\ell n} = O_{\ell m}\left(-1 + \frac{1}{8\pi^2}\,\frac{m_H^2}{\langle\eta\rangle^2}\,\ln\frac{M_{R_m}}{m_H}\right)O_{nm}$$

$$i,\ j,\ k,\ \ell,\ m,\ n = 1,\ 2,\ 3.$$

$O_{\ell m}$ is a matrix which diagonalizes the right neutrino mass matrix $\mathcal{M}_R$. M_{R_m} are eigenvalues of matrix $\mathcal{M}_R$.

Consider now a case when field Φ is complex, $\Phi = \begin{pmatrix} \delta^\circ & \xi^+ \\ \delta^- & -\bar{\xi}^\circ \end{pmatrix}$, which usually takes place. If we assume that there exists only one light Higgs doublet $\eta_1 = \cos\beta\cdot\delta + \sin\beta\cdot\xi$ ($\langle\eta_1\rangle \equiv \langle\eta\rangle = 175$ GeV), then the other doublet, $\eta_2 = -\sin\beta\cdot\delta + \cos\beta\cdot\xi$, has a mass of the order of (B-L) symmetry breaking and a zero v.e.v. $\langle\eta_2\rangle = 0$ (i.e. $tg\,\beta = \dfrac{\langle\xi^\circ\rangle}{\langle\delta^\circ\rangle}$).

As a result we have the following neutral fields with masses:

$$H_{gold} = \frac{\eta_1^\circ - \bar{\eta}_1^\circ}{i\sqrt{2}} \qquad m_{gold} = 0$$

$$H_{sw} = \frac{\eta_1^\circ + \bar{\eta}_1^\circ}{\sqrt{2}} \qquad m_{sw} \equiv m_H \tag{10}$$

$$H_1 = \frac{\eta_2^\circ - \bar{\eta}_2^\circ}{i\sqrt{2}} \qquad M_1 \simeq M_2 \equiv M_H \sim M_R$$

$$H_2 = \frac{\eta_2^\circ + \bar{\eta}_2^\circ}{\sqrt{2}} \qquad M_1^2 - M_2^2 = \lambda < \eta\ .\quad (\ldots)\,.$$

These all make a contribution to the left neutrino mass (Fig.4).

Hence for the light neutrino mass we have

$$m_1 = \frac{m^{\mathcal{D}2}}{M_R}\left[-1+\frac{1}{8\pi^2}\;\frac{m_H^2}{\langle\eta\rangle^2}\,\ln\frac{M_R}{m_H}+\frac{\lambda}{4\pi^2}\,tg^2\beta\,\frac{1}{1-\frac{M_H^2}{M_R^2}}\left(-1+\frac{\ln\frac{M_R^2}{M_H^2}}{1-\frac{M_H^2}{M_R^2}}\right)\right]. \quad (11)$$

With account of several generations the mass matrix of left neutrino has a form:

$$\mathcal{M}^{\nu}_{ij} = \mathcal{M}^{\mathcal{D}}_{iK}\,(\mathcal{M}_R^{-1})_{K\ell}\,B_{\ell n}\,\mathcal{M}^{\mathcal{D}}_{jn},$$

where

$$B_{en} = -I + O_{em}\frac{1}{4\pi^2}\left\{\frac{m_H^2}{2\langle\eta\rangle^2}\,\ln\frac{M_{Rm}}{m_H}+\lambda tg^2\beta\,\frac{1}{1-\frac{M_H^2}{M_{Rm}^2}}\left[-1+\frac{\ln\frac{M_{Rm}^2}{M_R^2}}{1-\frac{M_H^2}{M_{Rm}^2}}\right]\right\}. \quad (12)$$

At $tg\beta > 10$ and $\min(M_{Rm}) < M_H < \max(M_{Rm})$ the matrix B_{en} strongly differs from the unit one. Hence, in this case the light neutrino mixing matrix will chenge too, compared to the usual "see-saw" mechanism. Thus, one should necessarily take into account the radiative corrections to the neutrino mass matrix (1) when dealing with models with two Higgs field doublets where $tg\beta > 10$.

If $\min(M_{Rm}) > M_H$, then matrix B_{en} will be diagonal:

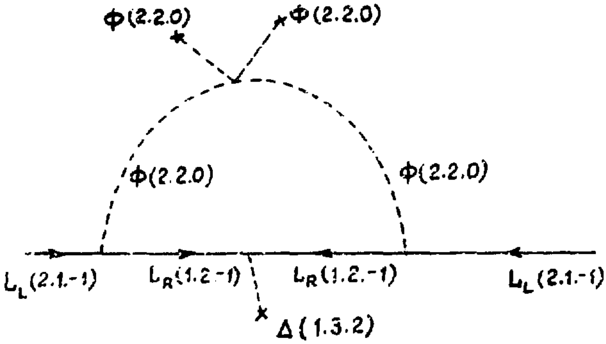
$$B_{en} = -I + \frac{1}{8\pi^2}\;\frac{m_H^2}{\langle\eta\rangle^2}\,\ln\frac{M_R}{m_H} + \frac{\lambda}{4\pi^2}\,tg^2\beta\left(\ln\frac{\tilde{M}_R}{M_H^2}-1\right). \quad (13)$$

Here we have neglected the difference of masses M_{Rm}. If we require such fine tuning of lagrangian parameters that $|B_{en}| \ll 1$, then masses of all light neutrino will be strongly suppressed compared to the usual "see-saw" mechanism. In this case strong right currents may take place ($M_{W_R} \sim 1$ TeV).

In the latter case large magnetic transfer moments are possible in neutrino, and the problem of the lack of solar neutrino can be solved. At the same time the problem of too rapid cooling of a supernova which took place in case of Dirac neutrino no longer arises.

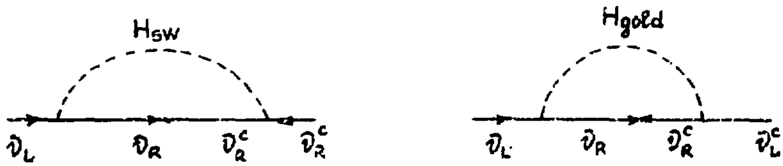
Thus, the above analysis points out a necessity to take into account radiative corrections to the neutrino mass matrix. Under certain conditions radiative corrections can greatly affect neutrino masses and mixing.

In conclusion, the authors would like to express their gratitude to Z.G. Berezhiani, M. Vysotsky, S.G. Matinyan and K.A. Ter-Martirossyan for the useful discussions.



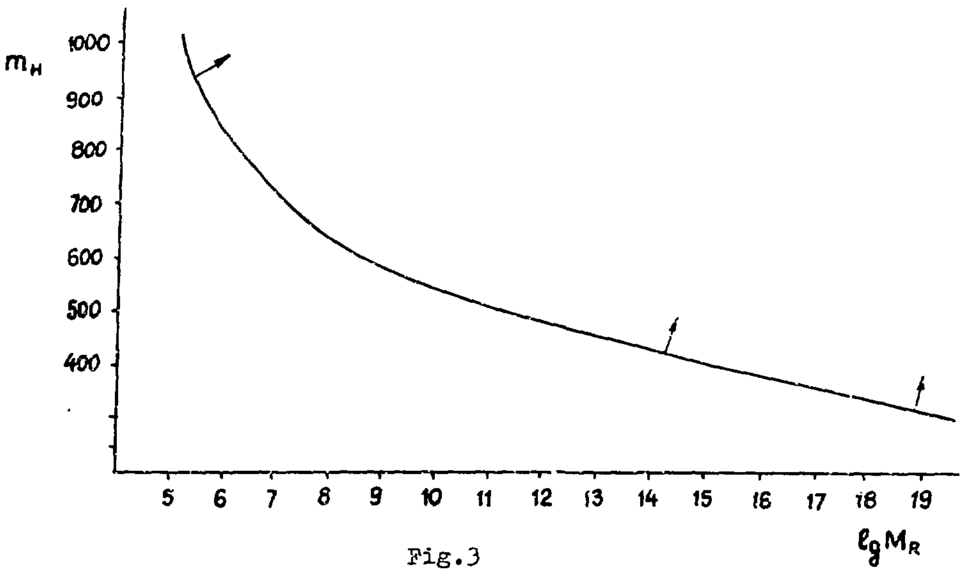
Φ(2.2.0)
Φ(2.2.0)
Φ(2.2.0)
Φ(2.2.0)
L_L(2.1.-1)
L_R(1.2.-1)
L_R(1.2.-1)
L_L(2.1.-1)
Δ(1.3.2)

Fig.1



H_SW
ν_L
ν_R
ν_R^c
ν_R^c
H_gold
ν_L
ν_R
ν_R^c
ν_L^c

Fig.2


m_H
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600
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7
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9
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11
12
13
14
15
16
17
18
19
$\lg M_R$

Fig.3

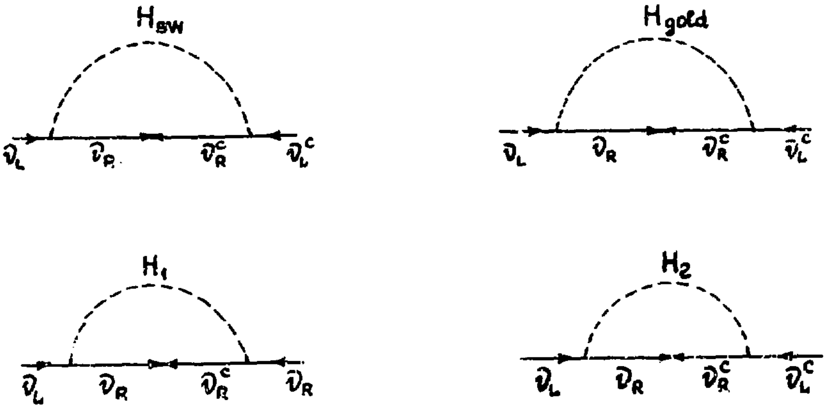
H_{SW}
ν_L
ν_R
ν_R^c
ν_L^c
H_{gold}
ν_L
ν_R
ν_R^c
$\bar{\nu}_L^c$
H_1
$\bar{\nu}_L$
ν_R
ν_R^c
$\bar{\nu}_R$
H_2
ν_L
ν_R
ν_R^c
ν_L^c

Fig.4

Figure Captions

Fig.1. A diagram that contributes to the left neutrino mass. Fields are given in the $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ group representation.

Fig.2. A diagram that contributes to the majorana mass of left neutrino in terms of ordinary fields.

Fig.3. Arrows point out regions where a radiative correction to the light neutrino mass is larger than the tree approximation (M_R and m_H are measured in GeV).

Fig.4. Diagrams that contribute to the left neutrino mass in the presence of two Higgs field doublets in theory.

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The manuscript was received 14 February 1989

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МАССЫ НЕЙТРИНО В ЛЕВО-ПРАВО СИММЕТРИЧНЫХ МОДЕЛЯХ

(на английском языке, перевод Асланян З.Н.)

Редактор Л.П.Мукаян

Технический редактор А.С.Абрамян

Подписано в печать 25/У-89г. БФ-02060 Формат 60х84/16

Офсетная печать.Уч.изд.л. 0,5 Тираж 299 экз. Ц. 8 к.

Зак.тип.№ 780 Индекс 3649

Отпечатано в Ереванском физическом институте

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