EFI

Preprint ~~YERP~~HI-1073(36)-88

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ
ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ
YEREVAN PHYSICS INSTITUTE

H.M.ASATRYAN

TWO HIGGS DOUBLETS IN SO(10)-MODEL

ЦНИИатоминформ
ЕРЕВАН 1988

Նախնատիպ ԵՖԻ-1073(36)-88

Հ.Մ. ԱՍԱՏՐՅԱՆ

ԵՐԿՈՒ ՀԻԳՍԻ ԴՈՒԲԼԵՏՆԵՐԸ SO(10) ՄՈԴԵԼՈՒՄ

Առաջարկվում է մեծ միավորման SO(10) մոդել՝ երկու թեթև Հիգսի դուբլետներով, որոնց վակուումային միջինները կապված են էլեկտրաթույլ $SU(2)_L\ U(1)_y$ խմբի խախտման հետ: Չեզոք հոսանքների բացակայության հետ կապված բնականության պայմանը հաշվի առնելով, մենք ստանում ենք որոշակի տեսքի քվարկային զանգվածային մատրիցներ, ինչպես նաև՝ խիստ սահմանափակումներ SO(10) մոդելում պրոտոնի կյանքի տևողության համար:

Երևանի Ֆիզիկայի Ինստիտուտ
Երևան 1988

Preprint YERPHI-1073(36)-88

H.M. ASATRYAN

TWO HIGGS DOUBLETS IN SO(10)-MODEL

A grand unified SO(10)-model with two light Higgs doublets whose vacuum expectation values are connected with breaking of electroweak $SU(2)_L \times U(1)_y$ group is proposed. Taking into account the naturality condition connected with the absence of flavor changing neutral currents, we obtained a definite form for the quark mass matrices. In this case we obtain rigid restrictions for proton lifetime in the SO(10)-model.

Yerevan Physics Institute
Yerevan 1988

Препринт ЕФИ-1073(36)-88

Г.М.АСАТРЯН

ДВА ДУБЛЕТА ХИГГСА В SO(10)-МОДЕЛИ

Предлагается модель великого объединения SO(10) с двумя легкими дублетами Хиггса, вакуумные средние которых связаны с нарушением электрослабой группы $SU(2)_L \times U(1)_y$. С учетом условия натуральности, связанной с отсутствием нейтральных токов, с изменением аромата, мы приходим к определенному виду для массовых матриц кварков. При этом получаются сильные ограничения для времени жизни протона в SO(10) - модели.

Ереванский физический институт
Ереван 1988

It is known that a simplest grand unified model based on SU(5) group cannot explain recent experimental restrictions for proton lifetime. In view of this, it seems natural to turn to SO(10)-model which is the simplest (after SU(5)) model of grand unification. As distinct from SU(5), the breaking of SO(10) group up to $G_0 = SU(3)^c \times SU(2)_L \times U(1)_y$ may consist of several steps. It can be shown that a larger (compared to SU(5)) proton lifetime in SO(10) model can be obtained only in the case if in SO(10) breaking there is an intermediate symmetry $G = SU(4) \times SU(2)_L \times SU(2)_R$ or $G' = SU(3) \times U(1) \times SU(2)_L \times \times SU(2)_R$, and only such breaking schemes are senseful to be considered [1-4] .

However for such SO(10) breaking schemes with one light Higgs-field doublet there exists a difficulty with fermion mass spectrum [5] . This difficulty was overcome in our proposed model with additional discrete symmetry [6,7] . We have succeeded in obtaining definite predictions for proton lifetime in SO(10)-model with one light Higgs doublet, which can be checked experimentally [8] .

In the present paper we study problems related to quark masses and mixing as well as to proton lifetime in SO(10)-model with two light Higgs doublets, whose vacuum expectation values (v.e.v.) are connected with electroweak subgroup breaking.

First, consider the case when fermions receive mass owing to interaction [illegible] generations):

$$\lambda_{ij}\, \underline{16}_i\, \underline{16}_j\, \underline{10} + \mu_{ij}\, \underline{16}_i\, \underline{16}_j\, \underline{10}^* + c.c. \qquad (1)$$

As was already mentioned, we consider only those SO(10) breaking schemes where intermediate symmetry G_0 or G' is present. In this case the interaction of quarks with Higgs fields responsible for G_0 breaking can be written as

$$\lambda_{ij}\, \overline{\Psi}_{Li}\, \varphi\, \Psi_{Rj} + \mu_{ij}\, \overline{\Psi}_{Li}\, \tilde{\varphi}\, \Psi_{Rj} + c.c.$$

$$\Psi_1 = \begin{pmatrix} u \\ d \end{pmatrix}, \quad \Psi_2 = \begin{pmatrix} c \\ s \end{pmatrix}, \quad \Psi_3 = \begin{pmatrix} t \\ b \end{pmatrix} \qquad (2)$$

$$\varphi = \begin{pmatrix} \eta^0 & \xi^+ \\ \eta^- & -\xi^{0*} \end{pmatrix} \qquad \tilde{\varphi} = \begin{pmatrix} \xi^0 & \eta^+ \\ \xi^- & -\eta^{0*} \end{pmatrix}$$

where $\eta = \begin{pmatrix} \eta^0 \\ \eta^- \end{pmatrix}$ and $\xi = \begin{pmatrix} \xi^0 \\ \xi^- \end{pmatrix}$ form $SU(2)_L$ doublets, and φ is (1,2,2) component of field $\underline{10}$ in the decomposition under the group G .

According to our assumption, both η and ξ doublets receive nonzero v.e.v. of M_W order and have mass of the same order. It is clear that in such a situation, generally speaking, the flavor changing neutral currents will arise. In order to forbid them, we must impose some unnatural smallness conditions on Yukawa coupling constants λ_{ij} , μ_{ij} . Here we shall hold the viewpoint that flavor conservation must be natural, must follow from the symmetry principles proper and must not demand imposing any additional hierarchical conditions in our grand unified SO(10) theory. We'll satisfy these principles if we assume that the following discrete symmetry takes place:

$$\underline{10} \longrightarrow i\,\underline{10}\,, \qquad \underline{16_i} \longrightarrow e^{-\frac{i\pi}{4}}\,\underline{16_i} \tag{3}$$

Then in (2) only the first term survives, and the flavor changing neutral currents are absent. In this case the mass matrices of up and down quarks take the form:

$$\mathcal{M}_u = \lambda_{ij}\langle\eta^0\rangle\,, \qquad \mathcal{M}_d = -\lambda_{ij}\langle\xi^{0*}\rangle \tag{4}$$

From (4) we obtain that all Kobayashi-Maskawa mixing angles are zero as well as the relation $m_u : m_c : m_t = m_d : m_s : m_b$, this, of course, being inapplicable. To obtain nonzero mixing angles, we, keeping the assumption on the existence of two light Higgs doublets, introduce a second field $\underline{10}'$ which transforms under discrete symmetry as $\underline{10}$: $\underline{10}' \to i\,\underline{10}'$.

Consider now a mass matrix of doublets η', ξ', η, ξ entering $\underline{10}'$ and $\underline{10}$. With respect to discrete symmetry, this mass matrix can be reduced to the form:

$$\begin{pmatrix} \mathcal{A}+B & 0 & C & 0 \\ 0 & \mathcal{A}-B & 0 & -C \\ C & 0 & \mathcal{D}+E & 0 \\ 0 & -C & 0 & \mathcal{D}-E \end{pmatrix} \qquad (5)$$

For what follows there will be important a mechanism of $SU(2)_R$ -symmetry breaking: this group can be broken either immediately or in two steps. Correspondingly, we shall consider two possible schemes of SO(10) breaking by the v.e.v. of Higgs fields $\underline{45}$, $\underline{126}$:

$$\begin{aligned} SO(10) &\xrightarrow{\langle(15,1,1)_{45}\rangle = M_X} SU(3)\times U(1)\times SU(2)_L\times SU(2)_R \\ &\xrightarrow{\langle(\overline{10},1,3)_{126}\rangle = M_R} SU(3)\times SU(2)_L\times U(1)_y \end{aligned} \qquad (6)$$

$$\begin{aligned} SO(10) &\xrightarrow{\langle(15,1,1)_{45}\rangle = M_X} SU(3)\times U(1)\times SU(2)_L\times SU(2)_R \\ &\xrightarrow{\langle(1,1,3)_{45}\rangle = M_R} SU(3)\times U(1)\times SU(2)_L\times U(1)_R \\ &\xrightarrow{\langle(\overline{10},1,3)_{126}\rangle = M_R^0} SU(3)\times SU(2)_L\times U(1)_y \end{aligned} \qquad (7)$$

Fields $\underline{45}$, $\underline{126}$ are assumed to be singlets of our introduced discrete symmetry.

The breaking scheme (6) was studied in detail in Ref.[2] where we have found the dependence of M_X and M_R on Weinberg angle in two-loop approximation. In case when $SU(2)_R$ is broken in two steps, the results of Ref.[2] are valid too, since the quantity M_R^0 drops out of renorm-group equations [3] and can be even of 1 TeV order. SO(10) breaking in both schemes may proceed through additional intermediate step G, but as will be seen further, this won't practically affect our results.

Let us turn now to the Higgs mass matrix (5) and see what is the order of magnitudes of this matrix elements. It differs for the two breaking schemes under consideration: for the breaking scheme (6) quantities $\mathcal{A}$, $\mathcal{D}$, generally speaking, are of M_X^2 order, while B, E, C of M_R^2 order. In case of breaking scheme (7), $\mathcal{A}$ and $\mathcal{D}$ are again of M_X^2 order, and B, E, C, generally speaking, are already of $M_X M_R$ order. This is due to the fact that, say, the term C in the mass matrix in the first case arises from the coupling $\underline{\overline{10}}^{*}\ \underline{10}'\ \underline{126}\ \ \underline{\overline{126}}$, and in the second case from $M_X \cdot \underline{\overline{10}}^{*}\ \underline{10}'\ \ \underline{45}$.

Pass now to diagonalization of mass matrix (5). Following our assumption, we must have two light Higgs fields; hence the mass matrix (5) is to have two eigenvalues of M_W^2 order. For that we must impose two fine-tuning conditions in order to obtain masses of M_W^2 order from the quantities $\sim M_X^2$, $M_R^2 \gg \gg M_W^2$. Eigenvalues of matrix (5) have the form:

$$2x_{1,2} = (\mathcal{A}+B)+(\mathcal{D}+E) \pm \left\{\left[(\mathcal{A}+B)-(\mathcal{D}+E)\right]^2+4C^2\right\}^{1/2}$$
$$2x_{3,4} = (\mathcal{A}-B)+(\mathcal{D}-E) \pm \left\{\left[(\mathcal{A}-B)-(\mathcal{D}-E)\right]^2+4c^2\right\}^{1/2} \tag{8}$$

The survival hypothesis for the Higgs fields [9] to be followed by us demands that the number of fine-tuning conditions would be minimal (two in the given case). Accordingly, two eigenvalues of (8) (e.g. X_2 and X_4) must be of M_W^2 order, and other two (X_1 , X_3) of M_X^2 order. Then one can easily show that for this case the conditions $\mathcal{A} \gg \mathcal{D}$ or $\mathcal{D} \gg \mathcal{A}$ must hold. Only the first case can be considered without restriction of generality. Let us find diagonal states of mass matrix (5):

$$\begin{aligned}
\eta_1 &= \eta\cos\theta + \eta'\sin\theta & \qquad tg\,2\theta &= -\frac{2c}{\mathcal{A}-\mathcal{D}} \\
\eta_2 &= -\eta\sin\theta + \eta'\cos\theta & & \\
\xi_1 &= \xi\cos\theta' + \xi'\sin\theta' & \qquad tg\,2\theta' &= \frac{2c}{\mathcal{A}-\mathcal{D}} \\
\xi_2 &= -\xi\sin\theta' + \xi'\cos\theta' & &
\end{aligned} \tag{9}$$

where eigenvalues $\sim M_W^2$ correspond to η_1 and ξ_1 states.

With respect to dicrete symmetry the interaction of quarks with Higgs fields has the form:

$$\lambda_{ij}\bar{\Psi}_{Li}\varphi\Psi_{Rj} + \lambda'_{ij}\bar{\Psi}_{Li}\varphi'\Psi_{Rj} + c.c. \qquad i,j = 1,2,3 \tag{10}$$

If by u_{Ri} (i =1,2,3) we denote the right components of u , c and t quarks, and by d_{Ri} the right components of d , s and b quarks and pass to diagonal states of Higgs fields, then 10 can be rewritten as

$$\begin{aligned}
&\bar{\Psi}_{Li}\{\eta_1(\lambda_{ij}\cos\theta + \lambda'_{ij}\sin\theta) + \eta_2(-\lambda_{ij}\sin\theta + \lambda'_{ij}\cos\theta)\}u_{Rj} + \\
&\bar{\Psi}_{Li}\{\xi_1(\lambda_{ij}\cos\theta' + \lambda'_{ij}\sin\theta') + \xi_2(-\lambda_{ij}\sin\theta' + \lambda'_{ij}\cos\theta')\}d_{Rj}
\end{aligned} \tag{11}$$

One can see that interaction (11) provides the absence of flavor changing neutral currents owing to superlarge masses ($\sim M_X$) of η_2 and ξ_2 doublets. Masses of up and down quarks occur due to v.e.v. of η_1 and ξ_1 doublets:

$$\mathcal{M}u = \langle \eta_1^0 \rangle \left(\lambda - \lambda' \frac{c}{\mathcal{A}-\mathcal{D}} \right)$$
$$\mathcal{M}d = -\langle \xi_1^{0*} \rangle \left(\lambda - \lambda' \frac{c}{\mathcal{A}-\mathcal{D}} \right) \qquad (12)$$

Mixing angles of Higgs field doublets $\theta = -\theta' = -c/(\mathcal{A}-\mathcal{D})$ are small, since $\mathcal{A} \sim M_X^2 \gg \mathcal{D}$, and C by order of magnitude is no larger than M_R^2 in the case of breaking scheme (6) and $M_R M_X$ in the case of breaking scheme (7). From this follows that the second term in quark mass matrices (12), proportional to λ_{ij} , may be considered small. We have already considered the mass matrices of (12) type in Ref.[8] . After diagonalization of these matrices we'll obtain the following restrictions for mixing angles [8] :

$$\sqrt{\frac{m_d}{m_s}} - \frac{m_b}{m_s} \sin\gamma \sin\beta < \sin\theta_c < \sqrt{\frac{m_d}{m_s}} + \frac{m_b}{m_s} \sin\gamma \sin\beta$$

$$\frac{m_s}{m_b}(1-\sin^2\theta_c) - \frac{m_c}{m_t} - \frac{2\sin\beta\sin\theta_c}{1-\sin^2\theta_c} \left| \frac{m_s}{m_b}(1-\sin^2\theta_c) - \frac{m_c}{m_t} \right| c \qquad (13)$$

$$< \sin^2\gamma < \frac{m_s}{m_b}(1-\sin^2\theta_c) + \frac{m_c}{m_t} + \frac{2\sin\beta\sin\theta_c}{1-\sin^2\theta_c} \left(\frac{m_s}{m_b}(1-\sin^2\theta_c) + \frac{m_c}{m_t} \right)$$

these leading to restriction of t-quark mass $m_t < 1{,}2\, m_b m_c/m_s$.

Thus, the quark mass matrices (12) ensure Kobayashi-Maskawa mixing angles consistent with experiment, but the values of these angles are proportional to M_R^2/M_X^2 for the scheme (6) and to M_R/M_X for the scheme (7). This in turn leads to some restrictions for the quantity M_R/M_X, since the Yukawa coupling constants λ'_{ij} are not absolutely arbitrary: in order the perturbation theory be valid, their upper limit must be in the region of unity. On the other hand, there exists a definite relation between the mass of SO(10) grand unification, M_X, and the mass of SU(5) grand unification, M_5 [2] : $M_X = M_5 (M_X/M_R)^{0,23}$. We can conclude that the values of M_X cannot differ significantly from the values of M_5, otherwise we won't obtain experimentally consistent values for quark mixing angles in the left charged currents. Hence, the proton lifetime in SO(10) model cannot be too large compared to predictions for proton lifetime in SU(5) model:

$$\tau_p(SO(10)) \leqslant (30-70)\,\tau_p(SU(5)) \qquad (14)$$

in the case of breaking scheme (6), and

$$\tau_p(SO(10)) \leqslant (600-5000)\,\tau_p(SU(5)) \qquad (15)$$

in the case of breaking scheme (7). The uncertainty in coefficients (14), (15) results from the uncertainties in Yukawa coupling components.

Exactly the same restrictions were obtained in Ref.[8], where the case with one light Higgs field doublet was considered. Actually relations (14), (15) are more restrictive, since the proton lifetime in SU(5) model in case of the second light doublet added is by a factor of ~ 10 lower.

We may conclude that in connection with experimental restriction of $\tau(p \to e^{+}\pi^{0}) > 3 \cdot 10^{32}$ years the SO(10) breaking scheme (6) with two light Higgs doublets is excluded. The breaking scheme (7) does not as yet contradict experimental restriction for proton lifetime, but it brings to the existence of new gauge neutal boson whose mass may be in the region of 1 TeV, which can be checked experimentally. As to the possible additional step of breaking connected with G group, here, since M_R does not differ considerably from M_X, the intemediate scale introduced between them will not practically change the situation.

Thus, we have considered the SO(10) grand unified model with two light Higgs field doublets. It is shown that if we follow the principle of natural conservation of flavors in weak neutral currents, then we'll obtain definite restrictions for the form of quark mass matrices and mixing angles in weak left charged currents. Restrictions for the proton lifetime in the SO(10) model are also obtained. These restrictions can be brought to agreement with the experimental limit for proton lifetime only in such SO(10) breaking scheme where new neutral gauge boson with the mass region of 1 TeV exists.

In conclusion the author would like to express his sincere gratitude to S.G. Matinyan and A.G. Sedrakyan for the useful discussion.

REFERENCES

1. Tosa J., Branco G.C., Marshak R.E. Constraints on proton lifetime and $\sin^2\theta_W$ in SO(10) grand unified theory. - Phys.Rev.D, 1983, v.28, p.1731.
2. Асатрян Г.М., Иоаннисян А.Н. Время жизни протона в модели великого объединения SO(I0). ЯФ, I985, т.4I, с.I097. Препринт ЕФИ-726(46)-84, Ереван I984.
3. Gipson J.M., Marshak R.E. Intermediate mass scales in the new SO(10) grand unification on the one loop approximation. - Phys.Rev.D, 1985, v.31, p.1705.
4. Chang D et al. Experimental tests of new SO(10) grand unification. - Phys.Rev.D, 1985, v.31, p.1718.
5. Световой В.Б. Промежуточная симметрия в SO(I0) модели и массы тяжелых кварков. Письма в ЖЭТФ, I983, т.37, с.49.
6. Асатрян Г.М. Иерархия масштабов нарушения в теории великого объединения SO(I0) и массы кварков. ЯФ, I987, т.45, с.II77.
7. Asatryan H.M. Symmetry breaking in SO(10) grand unified theory and quark masses. - Preprint YERPHI-961(11)-87, Yerevan, 1987.
8. Asatryan H.M. Quark masses and mixing in SO(10) model. - Preprint YERPHI-1048(11)-88, Yerevan, 1988.
9. Mahapatra R.N., Senjanovic G. Higgs boson effects in grand unified theories. - Phys.Rev.D, 1983, v.27, p.1601.

The manuscript was received 3 March 1988

Г.М.АСАТРЯН

ДВА ДУБЛЕТА ХИГГСА В SO (IO) - МОДЕЛИ

(на англиском языке перевод З.Н.Асланян)

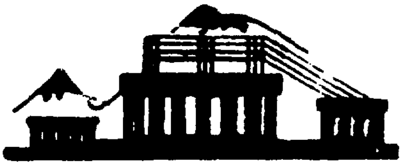
Редактор Л.П.Мукаян
Технический редактор А.С.Абрамян

Подписано в печать7/УI-88г. ВФ-03I49 Формат 60х84/I6
Офсетная печать.Уч.изд.л. 0,5 Тираж 299 экз.Ц.8 к.
Зак.тип.№ 274 Индекс 3624

Отпечатано в Ереванском физическом институте
Ереван 36, Маркаряна 2

The address for requests:
Information Department
Yerevan Physics Institute
Markaryan St., 2
Yerevan, 375036
Armenia, USSR

индекс 3624



ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ