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ЦЕНТРАЛЬНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ ИНФОРМАЦИИ И ТЕХНИКО-ЭКОНОМИЧЕСКИХ ИССЛЕДОВАНИЙ ПО АТОМНОЙ НАУКЕ И ТЕХНИКЕ

H.M.ASATRYAN

PARTICLE MASSES IN SO(18) GRAND UNIFIED MODEL

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Г.М.АСАТРЯН

МАССЫ ЧАСТИЦ В МОДЕЛИ ВЕЛИКОГО ОБЪЕДИНЕНИЯ SO(18)

Рассматривается модель великого объединения, основанная на ортогональной группе SO(18). В модели присутствуют четыре обычных и четыре зеркальных семейства фермионов. Изучаются механизмы возникновения масс обычных и зеркальных частиц. Получена оценка на массу правого W_R - бозона, осуществляющего взаимодействие через правые токи.

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H.M.ASATRYAN

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The grand unified model based on the orthogonal group SO(18) is considered. The model includes four ordinary and four mirror fermion families. The mechanism of the generation of masses of ordinary and mirror particles is studied. The estimate for the masses of the right W_R-boson, that implements the interaction via right currents, is obtained.

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The orthogonal groups SO(18) are most convenient for the solution of the problem of family unification, since the gauge SO(N) theories are automatically anomaly-free and include quite naturally various SO(10) families.

Such models should meet certain requirements. According to the survival hypothesis [1], the fermion representation should be complex with respect to $G = SU^c(3) \times SU_L(2) \times U(1)$; only the fermions, that cannot acquire a G-invariant mass, have ordinary (not super heavy) masses. Besides, a constraint comes also from the asymptotic freedom condition in color: if the number of fermion families is more than eight, β_{QCD} becomes positive.

On the other hand, the spinor representation of the orthogonal groups SO(4n+2) (only such orthogonal groups have complex representations) is self-conjugate with respect to G for $n > 2$ and contains at least 16 fermion families for $n > 3$.

It has been shown in [2,3] that one may evade the above difficulties, proceeding from such a scheme of breaking of SO(4n+2) by super heavy vacuum expectation values (VEVs) of the Higgs fields, which along with G leaves a discrete symmetry D. The additional discrete symmetry D protects ordinary fermions from getting a super heavy mass due to the fact that the self-conjugate (with respect to G) parts of the fermion representation transform differently with respect to D. In this case, there are no problems with the asymptotic freedom in color either, since some fermions get a super heavy mass and the asymptotic freedom at our energies is unbroken.

The present paper is devoted to the study of the SO(18) grand unified model, based on the above breaking mechanism.

The fermion representation is identified in this model with the spinor representation of SO(18), which has the dimension $\underline{256}$. The group SO(18) contains the subgroup SO(10)xSO(8), and the spinor representation may be decomposed in representations of this subgroup:

$$\underline{256} = (16,8) + (\overline{16},8'), \tag{1}$$

where $\underline{8}$ and $\underline{8}'$ are two different real spinor representations of SO(8). The representation $\underline{16}$ of SO(10) corresponds to ordinary particles, and the representation $\underline{\overline{16}}$, to the so-called mirror particles, i.e. particles which interact with W-bosons via right currents.

We choose such a scheme of SO(18) breaking, that along with G, there remains a discrete symmetry D.

The Higgs fields in our model are as follows: totally antisymmetric tensor of the fifth rank χ_{ijknm} and totally symmetric tensor of the fourth rank $\varphi_{ijkn}(i,j,k,n,m=1,\ldots,18)$. As is shown in [2,3], the super large VEVs of these fields break SO(18) down to D x G, where the generating ele-

ment T of the discrete symmetry D has the form of the diagonal matrix 8 x 8 on the spinor representations $\underline{8}$, $\underline{8}'$ of SO(8)

$$T = \mathrm{diag}\,(1,1,1,1,i,i,-i,-i)$$
$$T' = \mathrm{diag}\,(-1,-1,-1,-1,i,i,-i,-i) \tag{2}$$

Then the decomposition of the spinor representation $\underline{256}$ with respect to the group D x SO(10) takes the form:

$$\underline{256} = 4\cdot(\underline{16}^{1} + \underline{\overline{16}}^{-1}) + 2\,(\underline{16}^{i} + \underline{\overline{16}}^{-i} + \underline{16}^{-i} + \underline{\overline{16}}^{i}), \tag{3}$$

where we have written the quantum number T as a top index. The self-conjugate (with respect to D x SO(10)) part of the fermion representation $2\,(\underline{16}^{i} + \underline{\overline{16}}^{-i} + \underline{16}^{i} + \underline{\overline{16}}^{-i})$ gets a super heavy mass via VEVs of the Higgs field χ_{ijknm}, only four $\underline{16}$ and four $\underline{\overline{16}}$ families stay massless at this stage of breaking and there arise no problems with the asymptotic freedom in $SU^c(3)$.

In the present paper we shall study the next stage of breaking, when G x D is broken down to D x $SU^c(3)$ x U(1), and the breaking is due to the VEVs of the same Higgs fields φ_{ijkn} and χ_{ijknm}. At this stage of breaking, both the particles in four left and four right families and W,Z-bosons get a mass.

It is known that till now nobody has found particles interacting with W-bosons via right currents, i.e. particles that enter into mirror families. This, apparently, comes to imply that their mass is large enough, tens or maybe hundreds of GeV (if they exist at all).

In our scheme masses of these particles, of course, cannot be much larger than those of W,Z-bosons, since the Higgs field VEVs, that give masses to mirror particles, also contribute to the masses of W,Z-bosons.

The decomposition of the fermion mass operator in SO(10) x x SO(8) reads

$$\begin{aligned} \underline{256} \times \underline{256} &= (16 \times 16,\ 1 + 28 + 35) + (\overline{16} \times \overline{16},\ 1 + 28 + 35') + \\ &\quad + 2\,(16 \times \overline{16},\ 8 + 56) \\ \underline{16} \times \underline{16} &= \underline{10} + \underline{120} + \underline{126} \\ \underline{16} \times \overline{16} &= \underline{1} + \underline{45} + \underline{210} \end{aligned} \qquad (4)$$

It is seen that ordinary and mirror families, in general, get masses via various VEVs, and it is possible to provide a different order of their mass. For example, if ordinary particles get a mass due to VEVs (10,35), the mirror particles get a mass due to (10,35').

However, there exists a more interesting possibility. Namely, we shall assume that in the tree approximation, only mirror particles (and W,Z-bosons) get a mass. Ordinary particles get a mass only due to radiative corrections [4]. Thus the hierarchy of masses of ordinary and mirror particles is automatically provided.

Thus, in order to break $G \to SU^c(3) \times U(1)$, we use the Higgs fields VEVs (10,35') from the decomposition of χ_{ijkmn}

$$\begin{aligned} (\underline{18})^5_{as} &= (1,56) + (10,35) + (10,35') + \\ &\quad + (45,56) + (120,28) + (210,8) + \\ &\quad + (126,1) + (\overline{126},1) \end{aligned} \qquad (5)$$

These VEVs give a mass to W,Z-bosons as well as to mirror fermions. If the Yukawa and gauge constants are considered to be of the same order, the mirror fermions should have a mass m_W, m_Z, i.e. ~ 100 GeV.

Masses of ordinary fermions are generated only due to radiative corrections.

The first nonvanishing contribution is made by the diagram in fig. 1. It is finite and results in the following fermion mass:

$$m(16) \approx \frac{g^4}{4\pi} \langle (1,56) \rangle^2 \, m(\overline{16})/M_G^2 \,, \qquad (6)$$

where M_G is the mass of super heavy intermediate bosons, which is related to the generation of super heavy VEVs of different components of φ_{ijkn} and χ_{ijkmn} [2,3] (in particular, (1,56)). If all these VEVs are considered to be of the same order, $M_G \sim g \langle (1,56) \rangle$, and we obtain the following relations between masses of ordinary amd mirror fermions: $m(16) \sim \alpha\, m(\overline{16})$, where α is the typical gauge constant ($\sim 1/100$) [4].

Thus, masses of mirror fermions appear to be nearly 100 times bigger than those of ordinary fermions.

Due to the presence of exact discrete symmetry D in our scheme, ordinary and mirror particles do not mix, since they have different quantum numbers T (+1 and -1, respectively).

Consider now the neutrino mass in ordinary and mirror families.

In our treatment the left neutrino in ordinary families gets a mass due to the mechanism proposed by Gell-Mann et al., i.e. by introducing an M Majorana mass much bigger than the m Dirac mass. In our case M is related to the VEV of $\overline{126}$-plet of SO(10) from (5), and m is the mass of the upper quark of the appropriate family. In the simplified case (when there is no mixing between families), the mass matrix of the neutrino has the form

$$\begin{pmatrix} 0 & m \\ m & M \end{pmatrix} \qquad (7)$$

After diagonalization we shall have two Majorana neutrinos in each ordinary family: a left neutrino (with a small mixture of the right one, if $M \gg m$) with a mass $m_{VL} \sim m^2/M$ and a right neutrino with a mass $\sim M$.

What can we say about the scale of M ? The experimental restriction on the neutrino mass gives $M > 10^3$ GeV. It should be noted that the mass of the W_R-boson, which implements the interaction via right currents, is generated due to the same VEV of $\overline{126}$-plet, and is also of the order of M.

In our approach the neutrinos in mirror families get a Majorana mass due to radiative corrections. The first nonvanishing contribution is made by the diagram in fig. 2. This contribution can be easily estimated, it is of the order of αM (the Higgs field $(10^4_s, 1)$ from the decomposition of φ_{ijkn} also obtain a super heavy VEV [2,3]). As a result, we have the following mass matrix for mirror neutrinos:

$$\begin{pmatrix} \alpha M & m(\overline{16}) \\ m(\overline{16}) & 0 \end{pmatrix} \qquad (8)$$

After diagonalization we shall obtain in each family two Majorana neutrinos with the masses $m^2(16)/\alpha M$ and αM, if $m(\overline{16}) \ll \alpha M$. In the case, if $m(\overline{16}) \sim \alpha M$, the neutrino will have the mass $\sim m(\overline{16})$.

On the other hand, for cosmological reasons, there is a restriction on the masses of heavy (with a mass > 1 MeV) neutrinos; their mass should be > 2 GeV [5]. Making use of this fact, we obtain $M < m^2(\overline{16})/\alpha \cdot 1$ GeV $\sim 10^6$ GeV. Thus, we have the following restrictions for M, and, hence, for the mass of the W_R-boson as well:

$$10^3 \text{ GeV} < m_{WR} < 10^6 \text{ GeV}$$

In ref. [6] a stronger restriction was obtained for the heavy neutrino mass: > 100 GeV. In this case we obtain for m_{WR} narrower limits

$$10^3 \text{ GeV} < m_{WR} < 10^4 \text{ GeV}.$$

The obtained limits for m_{WR} do not conflict with the restriction on the existence of right currents.

In refs. [4,7], O(14) and O'(14) symmetries are considered as flavor unifying groups. Unlike our model, where the discrete symmetry D provides the presence of fermions with ordinary masses, the fermion representation is there self-conjugate. This implies that the presence of ordinary masses of fermions in these models is attained artificially. Therefore, our model looks more natural.

Thus, SO(18) grand unified model, proposed in the present paper, allows to naturally unify different families into a unified scheme, obtain a reasonable estimate of the masses of mirror fermions and right W_R-bosons.

Other consequencies of the model will be studied in a subsequent paper.

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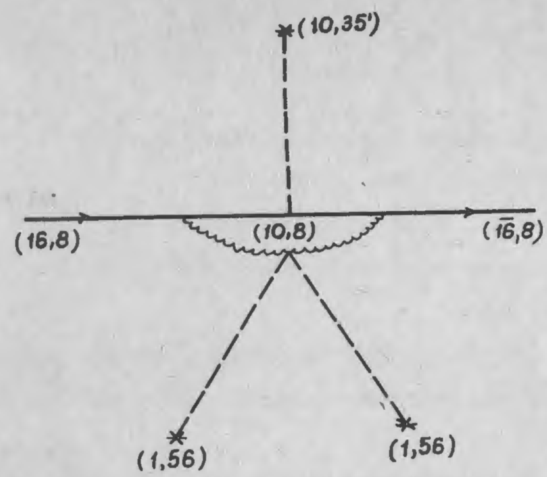

Fig. 1 Diagram of the lowest order contributing into ordinary fermion masses.

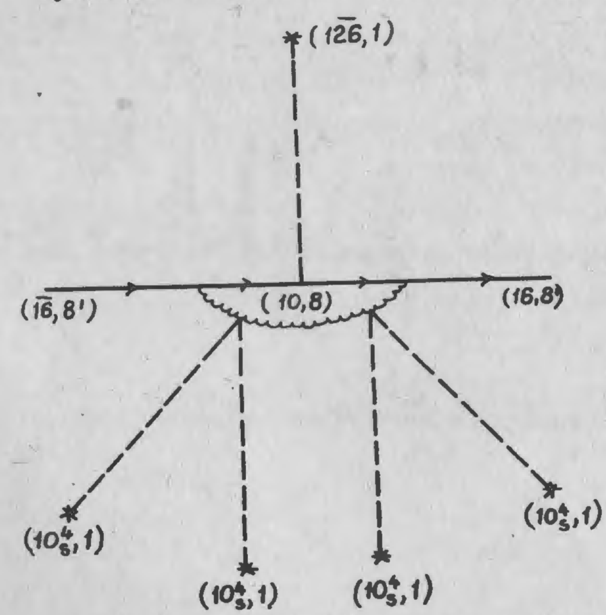

Fig. 2 Diagram of the lowest order contributing into the Majorana masses of neutrinos in mirror families.

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Г.М.АСАТРЯН

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