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HIERARCHY OF BREAKING SCALES IN $SO(10)$ GRAND
UNIFIED THEORY AND PARTICLE MASSES

ЦНИИатоминформ

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**SO(10) ՄԵՆ ՄԻԱՄՆԱՑՄԱՆ ՏԵՍՈՒԹՅԱՆ ԽԱՔՏՄԱՆ ՄԱՍՇՏԱՐՆԵՐԻ
ԳՈՒՄԱՆԱՐԳՈՒԹՅՈՒՆԸ ԵՎ ՄԱՍՆԻԿՆԵՐԻ ԶԱՆՎԱԾՆԵՐԸ**

Առաջարկված է փոխադրեցուծյունների մեծ միասնացման $SO(10)$ մոդել, որն օժտված է լրագուզիչ ընդհանուր համաչափությամբ: Դրա շնորհիվ մոդելում լուծված է քվարկների զանգվածի հետ կապված խնդիրը, որն առաջանում է $SO(10)$ -ի խախտման այնպիսի սխեմաներում, որոնք օժտված են միջանկյալ $SU(2)_R \times SU(2)_H$ - համաչափությամբ: Միայն մեկ թեթև չիզոսի Բոզոնի գոյությունն պայմանից, ստացված է $\bar{6}$ և 6 - քվարկների զանգվածների համար առնչություն, որը թույլ է տալիս որոշել մեծ միասնացման M_X և քվարկ-լեպտոնային համաչափության խախտման M_C մասշտաբի հարաբերությունը: M_X -ի արժեքը կախված է Վայնբերգի անկյան արժեքից և չի հակասում պրոտոնի արոման համար ստացված փորձնական արդյունքներին:

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H.M. ASATRYAN, A.N. IOANNISSYAN

HIERARCHY OF BREAKING SCALES IN $SO(10)$ GRAND
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We suggest a model of $SO(10)$ grand unification with additional discrete symmetry, where the quark mass spectra problem usually arising in $SO(10)$ breakdown schemes with intermediate $SU(2)_L \times SU(2)_R$ symmetry is solved. From the condition of existence of only one light Higgs boson we have obtained a relation between \bar{b} and t quarks masses which enables one to fix a ratio of grand unification scale M_X to quark-lepton symmetry breaking scale M_C . A concrete value of M_X depends on the Weinberg angle and is in agreement with the proton decay experiments.

Yerevan Physics Institute

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Г.М.АСАТРЯН, А.Н.ИОАННИСЯН
ИЕРАРХИЯ МАСШТАБОВ НАРУШЕНИЯ В ТЕОРИИ
БОЛЬШОГО ОБЪЕДИНЕНИЯ $SO(10)$ И МАССЫ ЧАСТИЦ

Предлагается модель большого объединения $SO(10)$ с дополнительной дискретной симметрией, где решена проблема с массовым спектром кварков, которая возникает в схемах нарушения

$SO(10)$ с промежуточной $SU(2)_L \times SU(2)_R$ -симметрией. Из условия существования только одного легкого бозона Хиггса получено соотношение между массами b и t кварков, которое позволяет зафиксировать отношение масштаба большого объединения M_X и масштаба нарушения кварк-лептонной симметрии M_C . Конкретное значение M_X зависит от угла Вайнберга и согласуется с экспериментами по распаду протона.

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It is known that a simplest model of grand unification, based on SU(5) group, cannot explain the recent experimental data on proton lifetime. Among other possible schemes the simplest one is the grand unified model based on SO(10) group. Just as the SU(5), this model contains only ordinary quarks and leptons as well as right neutrino.

It was shown in Refs. [1-4] that the proton lifetime larger than that in SU(5) can be obtained only in such SO(10) breaking schemes which include the intermediate symmetries $G = SU(4) \times SU(2)_L \times SU(2)_R$ or $G_1 = SU(3)_C \times U(1)_{B-L} \times SU(2)_L \times SU(2)_R$. It is here assumed that the breaking scales for the left-right discrete symmetry \mathcal{D} M_p and $SU(2)_R$ symmetry are decoupled [5]. However with such models, there arises the fermion mass problem pointed to by Svetovoy [6]. He has shown that in the models with intermediate $SU(2)_L \times SU(2)_R$ symmetry, under assumption of the existence of only one light (with mass $\sim M_W$) Higgs boson, the masses of b and t quarks turn out equal. In this paper we suggest the SO(10) grand unified model where we avoid this difficulty by means of the imposing of additional discrete symmetry.

Follow briefly arguments of Ref.[6]. Assume that at SO(10) breaking, there occurs an intermediate symmetry G or G_1 . For simplicity, let us suppose that all quarks and leptons obtain mass due to the interaction with

the vacuum expectation value (v.e.v.) of one complex Higgs field in $\underline{10}$ representation (this does not affect the generality of conclusions). The decomposition of $\underline{10}$ under G has the form: $\underline{10} = (6,1,1) + (1,2,2)$. Denote $\varphi = (1,2,2)$; namely this field obtains v.e.v. connected with $SU(2)_L$ symmetry breaking. φ can be expressed as 2×2 matrix:

$$\varphi = \begin{pmatrix} \eta^0 & \xi^+ \\ \eta^- & -\xi^{0*} \end{pmatrix}, \quad \tilde{\varphi} = -\varepsilon \varphi^* \varepsilon^T = \begin{pmatrix} \xi^0 & \eta^+ \\ \xi^- & -\eta^{0*} \end{pmatrix} \quad (1)$$

where for convenience we defined field $\tilde{\varphi}$ conjugated to φ , while $\xi = \begin{pmatrix} \xi^0 \\ \xi^- \end{pmatrix}$ and $\eta = \begin{pmatrix} \eta^0 \\ \eta^- \end{pmatrix}$ are usual $SU(2)_L$ spinors.

The mass term in the lagrangian for φ , $\tilde{\varphi}$ fields is as follows:

$$\mathcal{L}_M = \alpha M_1^2 (\varphi^+ \varphi + \tilde{\varphi}^+ \tilde{\varphi}) + \beta M_2^2 (\varphi^+ \tilde{\varphi} + \tilde{\varphi}^+ \varphi) \quad (2)$$

where M_1 , M_2 have, generally speaking, the order of mass of grand unification M_X . The diagonal states are $\varphi_{1,2} = \frac{1}{\sqrt{2}} (\varphi \pm \tilde{\varphi})$ with masses $\alpha M_1^2 \pm \beta M_2^2$

The fine tuning condition requires that one of these states (say, φ_1) should have mass of the order of M_W ; it is the Higgs field whose v.e.v. breaks the $SU(2)_L$ symmetry; the other field φ_2 must have mass of the order of M_X and v.e.v. equal to zero, in accordance with the generalized survival hypothesis [7]. The latter gives: $\langle \eta^0 \rangle = \langle \xi^0 \rangle$. Taking account of the fact that t and b quarks in the doublet $\Psi_{L,R} = \begin{pmatrix} t \\ b \end{pmatrix}_{L,R}$ obtain masses owing to couplings with φ and $\tilde{\varphi}$,

$$a \bar{\Psi}_L \varphi \Psi_R + b \bar{\Psi}_L \tilde{\varphi} \Psi_R \quad (3)$$

we get: $m_b = m_t$, this contradicting the experiment. This relation remains unchanged in case the Higgs sector is complicated. It may be broken only due

to corrections $\sim M_R/M_X$; however such corrections are small: for the proton lifetime to be sufficiently large, M_R must differ considerably from M_X .

To solve this problem, the author of Ref.[8] suggested to introduce additional heavy fermions, which allowed one to avoid undesirable equality of \bar{b} and \bar{t} quarks masses.

In the present work we suggest a model which allows one to solve this problem in a more economic and natural way. As compared to the usual $S(10)$ model, ours contains only additional discrete symmetry. Under the action of this discrete symmetry, $\underline{16}$ -plet of fermions and scalar fields $\underline{54}$, $\underline{210}$, $\underline{45}$, $\underline{126}$, $\underline{10}$, connected with $S(10)$ breaking transform as follows:

$$\begin{aligned}
 \underline{16} &\rightarrow e^{-i\frac{\pi}{4}} \underline{16}, & \underline{10} &\rightarrow i \underline{10} \\
 \underline{54} &\rightarrow \underline{54}, & \underline{210} &\rightarrow \underline{210} \\
 \underline{45} &\rightarrow -\underline{45}, & \underline{126} &\rightarrow -i \underline{126}
 \end{aligned} \tag{4}$$

The corresponding breaking scheme has the form:

$$\begin{aligned}
 S(10) \xrightarrow{\langle (1,1,1)_{54} \rangle = M_X} & SU(4) \times SU(2)_L \times SU(2)_R \times \mathcal{D} \\
 & \xrightarrow{\langle (1,1,1)_{210} \rangle = M_P} SU(4) \times SU(2)_L \times SU(2)_R \\
 & \xrightarrow{\langle (15,1,1)_{45} \rangle = M_e} SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{R-L} \\
 & \xrightarrow{\langle (\bar{10},1,3)_{126} \rangle = M_R} SU(3)_c \times SU(2)_L \times U(1)_Y
 \end{aligned} \tag{5}$$

where $(1,1,1)_{54}$, $(1,1,1)_{210}$, $(15,1,1)_{45}$, $(\bar{10},1,3)_{126}$ enter in the decomposition of the corresponding representations $\underline{54}$, $\underline{210}$, $\underline{45}$, $\underline{126}$ under the G . V.e.v. of fields $\underline{45}$, $\underline{126}$ break simultaneously our introduced discrete symmetry (4) as well.

The mass term for the Φ field we shall write down in terms of spinors η , ξ . Without account of breaking of discrete symmetry (4), the mass term is diagonal with respect to η , ξ :

$$\mathcal{L}'_M = (\alpha M_1^2 + \gamma M_R^2) \eta^* \eta + (\alpha M_1^2 - \gamma M_R^2) \xi^* \xi \quad (6)$$

where the term proportional to M_R^2 arises due to $\underline{10} \underline{10} \overline{126} \underline{126}$ interaction. Nondiagonal over η , ξ terms occur after the accounting of radiative corrections. The Figure shows the simplest diagrams leading to such terms. For estimates, one may regard all coupling constants at vertices identical, and masses of scalar particles (they all are of the order of M_X) passing within the inner lines can be regarded equal. Hence we shall obtain the nondiagonal over η , ξ mass term (diagrams α and β make contributions of the same order):

$$\Delta \mathcal{L}_M = \lambda \gamma \frac{M_c}{M_X} M_R^2 (\eta^* \xi + \xi^* \eta) \quad (7)$$

where λ is a typical coupling constant.

We assume that there exists only one Higgs field with a mass $\sim M_W$. Then, one of the eigenvalues of the mass matrix (6), (7) must be of the order of M_W^2 . In this case, the second $SU(2)_L$ doublet has the mass of the order of M_R . One can readily calculate the η , ξ mixing angle: $\text{tg } 2\theta = \frac{1}{2} \lambda \frac{M_c}{M_X}$. If bearing in mind that due to the discrete symmetry (4) the second term in (3) is forbidden, we shall get for the ratio of b and t quark masses (by a proper choice of signs of coupling constants one can always secure that m_b/m_t should enter into (8) rather than the inverse quantity):

$$\frac{m_b}{m_t} = \frac{1}{4} \lambda \frac{M_c}{M_X} \quad (8)$$

The estimate is true with the accuracy up to factors of about ten. It follows from the estimate that M_C (and hence M_p) cannot differ strongly from M_X , say, no more than by a factor of 10. We do not obtain constraints for the breaking scale of $SU(2)_R$ M_R from the quark mass spectrum.

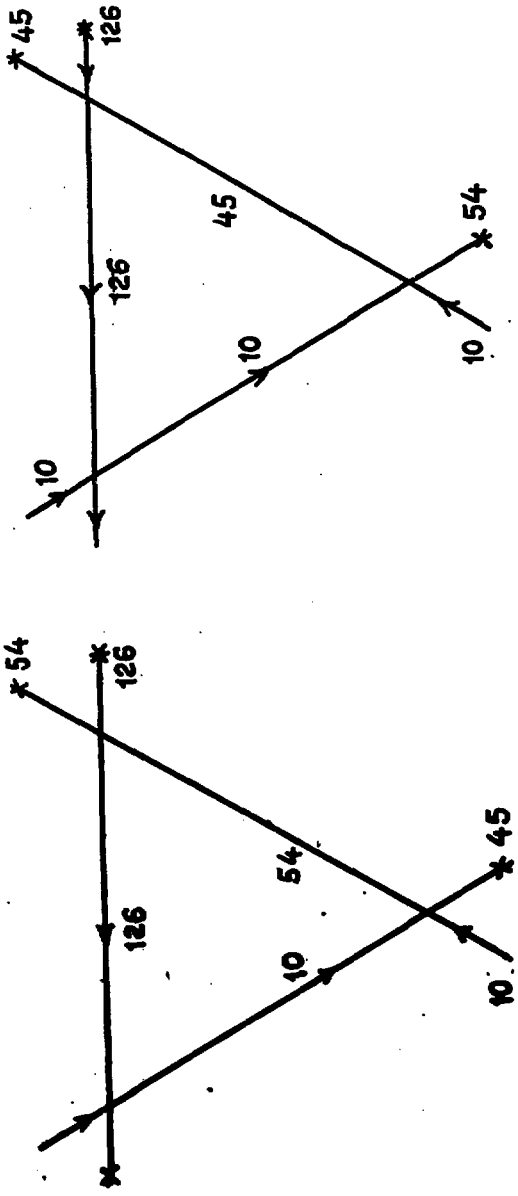
The obtained breaking scheme of $SO(10)$ gives for the proton lifetime practically the same results as those obtained in our previous work [2], where the breaking scheme of $SO(10)$ looks as follows:

$$SO(10) \xrightarrow{\langle (15, 1, 1)_{45} \rangle = M_X} G_1 \xrightarrow{\langle (\bar{10}, 1, 3)_{126} \rangle = M_R} G_0$$

The obtained renormalization group equations with account of the second loop make it possible to calculate M_X and M_R versus the Weinberg angle. The results will be true for the present model as well. With respect to the experimental value of the Weinberg angle $\sin^2 \theta_W = 0.22 \pm 0.02$ the largest value $M_X = 10^{16}$ GeV (for the value of parameter Λ of QCD $\Lambda = 0.16$ GeV), to which corresponds the proton lifetime $\tau_p \approx 10^{37}$ years, this being considerably larger than experimental limit.

Thus, we have suggested a model where by means of the introduction of discrete symmetry we succeed in avoiding the contradiction with fermion mass spectra, which arises in breaking schemes of $SO(10)$ with intermediate $SU(2)_L \times SU(2)_R$ symmetry. The obtained relation between \bar{b} and \bar{t} quark masses fixes a certain hierarchy of $SO(10)$ breaking scales. In this case, predicted proton lifetime agrees with the experiment.

In conclusion, the authors would like to express their sincere gratitude to S.G.Matinyan, R.L.Mkrtchyan and A.G.Sadrakyan for useful discussions.



a)

b)

Diagrams contributing to nondiagonal over η mass term.

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БОЛЬШОГО ОБЪЕДИНЕНИЯ $SO(10)$ И МАССЫ ЧАСТИЦ
(на английском языке, перевод З. Н. Асламян)

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