ЕФИ-817(44)-85

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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

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SUPERSYMMETRY AND INTERMEDIATE SYMMETRY BREAKING IN SO(10) SUPERUNIFICATION

ЦНИИатоминформ

ЕРЕВАН-1985

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и технико-экономических исследований по атомной науке
и технике (ЦНИИатоминформ) 1985г.

ЕФИ-617(44)-85

H.M. ASATRYAN, A.N. IOANNISYAN

SUPERSYMMETRY AND INTERMEDIATE SYMMETRY BREAKING IN SO(10) SUPERUNIFICATION

A superunified SO(10) model with simultaneous breakdown of supersymmetry and intermediate symmetry $SU(3)_c \times U(1) \times SU(2)_L \times SU(2)_R$ by means of a single scale parameter μ is suggested. Taking into account the quantum corrections to vacuum energy one can obtain unambiguously a physically acceptable breakdown scheme for SO(10) and intermediate symmetry up to the standard group $SU(3)_c \times SU(2)_L \times U(1)_y$. The breakdown parameter values $\mu \sim 10^{11} - 10^{12}$ GeV are in agreement with the Weinberg angle experimental value.

Yerevan Physics Institute

Yerevan 1985

ЕФИ-817(44)-85

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НАРУШЕНИЕ СУПЕРСИММЕТРИИ И ПРОМЕЖУТОЧНОЙ СИММЕТРИИ В ТЕОРИИ СУПЕРОБЪЕДИНЕНИЯ SO(10)

Предлагается модель суперобъединения SO(10) с одновременным нарушением суперсимметрии и промежуточной симметрии $SU(3)_c \times U(1) \times SU(2)_L \times SU(2)_R$ с помощью одного масштабного параметра μ. Учет радиационных поправок к вакуумной энергии позволяет однозначно получить [illegible] нарушения SO(10) и промежуточной симметрии до стандартной группы $SU(3)_c \times SU(2)_L \times U(1)_y$. Значения параметра нарушения $\mu \sim 10^{11} - 10^{12}$ ГэВ находятся в согласии с экспериментальным значением угла Вайнберга.

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Ереван 1985

The SO(10) grand unified theory. unlike SU(5), makes it possible to unite all fermions of the same generation into one irreducible representation. gives an acceptable solution of the question concerning the neutrino mass. Due to the fact that SO(10) includes a symmetry higher than that of the SU(5), the SO(10) breakdown may be followed by the occurence of an intermediate scale between the W -boson mass, M_W, and the grand unification mass, M_X. This scale is associated with the presence of intermediate symmetry involving the standard group $G_0 = SU(3)_c \times SU(2)_L \times U(1)_y$. On the other hand, the supersymmetry breakdown in the superunified theories also may take place in the intermediate between M_X and M_W region $\gg \sqrt{M_W \cdot M_X}$ [1]; in this case the mass splitting in supermultiplets of the ordinary particles occurs owing only to the quantum corrections and may be of the order of M_W [2,3]. It is not excluded that the scales of breakdown of the intermediate symmetry SO(10) and supersymmetry coincide.

The present work is devoted to studying a possibility of simultaneous breakdown of supersymmetry and intermediate symmetry by means of a single scale parameter μ in the SO(10) superunified theory.

The SO(10)-symmetry breakdown can proceed through one of its maximal subgroups: $SU(5) \times U(1)$ or $G = SU(4) \times SU(2)_L \times SU(2)_R$. For our purpose only the second version of breaking is nontrivial, i.e. when the scale μ

of the intermediate symmetry breakdown differs from the scale M_X connected with the proton decay [4,5]. The Pati-Salam G group is preferable also in the sense that in the schemes with such intermediate symmetry (or when the role of the intermediate symmetry is played by its subgroup $G_1 = SU(3)_c \times U(1) \times SU(2)_L \times SU(2)_R$) it is possible to obtain the Weinberg angle values more acceptable than in the supersymmetric SU(5)-model [6] . where the theoretical prediction for this angle exceeds somewhat its experimental value [7] . Note that of great importance is a content of the Higgs superfields breaking the intermediate symmetry G or G_1 up to G_0 : when for these Higgs superfields we take $\underline{126} + \overline{\underline{126}}$, the value of the Weinberg angle decreases against the supersymmetric SU(5), while in the case when the Higgs superfields are $\underline{16} + \overline{\underline{16}}$, the Weinberg angle increases [6,8] . The choice of $\underline{126} + \overline{\underline{126}}$ as the Higgs superfields is more suitable also because it allows one to solve the question concerning the neutrino mass. Therefore we shall follow this choice.

In this connection note the following circumstance. The decomposition of $\underline{126}$ under G has the form:

$$\underline{126} = (\overline{10}, 1, 3) + (10, 3, 1) + (15, 2, 2) + (6, 1, 1) \qquad (1)$$

One can see that this decomposition is symmetric under the operation of Hermitian conjugation and simultaneous replacement of $SU(2)_L$ by $SU(2)_R$. When the singlets G_0 being in $(\overline{10}, 1, 3)$ $\underline{126}$ and $(10, 1, 3)$ $\overline{\underline{126}}$ receive the vacuum expectation value (v.e.v.), thus breaking the intermediate symmetry G up to G_0 , particles in the supermultiplets $(\overline{10}, 1, 3) + (10, 1, 3)$ acquire a mass of the order of the μ breaking scale (except for the Goldstone particles). Due to the discrete symmetry mentioned, such mass may be obtained also by particles in the supermultiplets $(\overline{10},3,1) + (10,3,1)$, this being in contradiction with the survival hypothesis for the Higgs fields [9] . Besides, this discrete symmetry makes it difficult to understand why namely the right and not the left SU(2) group is broken at the μ scale: for we know that (10,3,1) + ($\overline{10}$,3,1) from $\underline{126}$ and $\overline{\underline{126}}$ also contain the $SU(3)_c \times U(1)_{em}$ -singlet whose v.e.v. can break the intermediate symmetry up to $SU(3)_c \times SU(2)_R \times U(1)$ and give the W -bosons the mass $\mu \gg M_W$.

In order to avoid this difficulty, in Ref.[8] is considered a model with intermediate symmetry $SU(3)_c \times U(1) \times SU(2)_L \times U(1)_R$, where the right group $SU(2)_R$ is broken already at the grand unification mass, M_X . As to us, we shall consider a possibility when the intermediate symmetry is G or G_1 with unbroken $SU(2)_R$, whereas the left-right discrete symmetry which is present in SO(10) is broken. As is mentioned in [10] , for that one can use the Higgs superfield $\underline{210}$ - antisymmetric tensor of rank four which has the following decomposition under G:

$$\begin{aligned} \underline{210} = {} & (15,1,1) + (15,1,3) + (15,3,1) + (6,2,2) + \\ & + (10,2,2) + (\overline{10},2,2) + (1,1,1) \end{aligned} \quad (2)$$

The singlet of G from (2), (1,1,1), changes its sign at the replacement of L by R, hence a v.e.v. of this superfield simultaneously with breaking of SO(10) up to G breaks also the discrete L-R symmetry.

Then owing to the coupling $\overline{\underline{126}}$ $\underline{210}$ $\underline{126}$ particles in supermultiplets ($\overline{10}$,1,3) and (10,3,1) from $\underline{126}$ (like (10,1,3) and ($\overline{10}$,3,1) from $\overline{\underline{126}}$) can obtain different masses, this making possible to avoid the above-mentioned difficulties.

The superpotential which gives rise to breakdown of the intermediate symmetry and supersymmetry we choose in the form:

$$W_1 = \alpha x(\overline{\underline{126}} \cdot \underline{126} - \mu^2) + \beta y \overline{\underline{126}} \cdot \underline{126} + \gamma z^2 x + M_1 z t \qquad (3)$$

where μ is the breakdown parameter, x, y, z, t are the chiral singlet superfields.

As to the SO(10) breakdown, it arises owing to the superpotential

$$W_2 = \lambda \; v\,(\underline{210}\;\underline{210} - M_2^2) \qquad (4)$$

where v is the SO(10) singlet.

It is necessary to write down also terms which give masses to particles from $\underline{126}$, $\overline{\underline{126}}$:

$$W_3 = M_3 \overline{\underline{126}}\;\underline{126} + \lambda_2 \overline{\underline{126}}\;\underline{126}\;\underline{210} \qquad (5)$$

where all mass parameters (except μ) in (3)-(5) are of the order of M_X. Superpotential $W_1 + W_2 + W_3$ gives, in principle, a correct picture of the breakdown; however its drawback is that not all particles in the superfield $\underline{210}$ receive masses of the order of the superunification mass M_X : even if adding a cubic 210 term to (4), the superfields (15,1,1), (10,2,2), ($\overline{10}$,2,2) from the decomposition (2) do not acquire such masses [11] . To solve this question one should introduce new superfields whose v.e.v. are connected with the SO(10) breakdown: one may introduce one more superfield $\underline{210}'$ or superfields $\underline{54}$ and $\underline{45}$.

The additional terms in the superpotential in the former case have the form:

$$W_4 = M_4(\underline{210}')^2 + \lambda_4(\underline{210}')^3 + \lambda_5(\underline{210})^2\,\underline{210}' + \lambda_6 \overline{\underline{126}}\;\underline{126}\;\underline{210}' + \lambda_7\,\underline{210}\cdot\underline{210}\cdot\underline{210}'\varepsilon \qquad (6)$$

where the last term is formed by means of a totally antisymmetric rank-ten invariant tensor ε , $M_4 \sim M_X$.

If $(1,1,1)_{210}$ and $(15,1,1)_{210'}$ in 210, 210' possess nonzero v.e.v., then owing to (4), (6) all particles in 210, 210' acquire superlarge masses (except for the Goldstone supermultiplets and the superfield $(1,1,1)_{210}$), whereas SO(10) is broken up to G_1 .

Irrespective of the question with 210-plet masses, the breakdown scheme $SO(10) \to SU(3)_c \times U(1) \times SU(2)_L \times SU(2)_R$ is more attractive against the scheme $SO(10) \to SU(4) \times SU(2)_L \times SU(2)_R$ for the following reason. In our scheme it is assumed that the right neutrino receives mass owing to the coupling $\underline{16}_f\ \underline{16}_f\ \underline{126}$., where $\underline{16}_f$ is a supermultiplet of the ordinary fermions. However owing to the same coupling, there arises an interaction between the fermion superfields and the color triplets entering (10,1,3) $\overline{126}$. As the particles entering this supermultiplet do not obtain mass of the order of M_X , this may lead to proton decay with relatively high probability [8]. The introduction of 210' with the v.e.v. of (15,1,1) makes it possible to split these color triplets off the singlet G_0 in (10,1,3) and owing to the last term in (6) to give a mass of the order of M_X to the triplets. So, there is no problem with the proton decay.

Quite similarly one can write down a superpotential for the case when instead of 210' we take the Higgs superfields 45 and 54 leading to the breakdown $SO(10) \to G_1$; note that in this case also all the superfields (except the Goldstone ones) from 45, 54, 210 obtain superlarge masses. We shall study at greater length a case with the 210-plets. The results of the both cases are quite similar.

Let us turn to searching for a minimum of the potential . As mentioned, a part of the potential which is independent of the fields 126, $\overline{126}$ has a minimum at $\langle (1,1,1)_{210} \rangle \sim \langle (15,1,1)_{210'} \rangle \sim M_X$, this leading to a breakdown of SO(10) up to G_1 . So when we search for the minimum associated with the breakdown of the intermediate symmetry and supersymmetry, the fields $\mathcal{V}$ $(15,1,1)_{210}$, $(1,1,1)_{210'}$, $(15,1,3)_{210}$, $(15,1,3)_{210'}$ containing G_0 singlets will obtain v.e.v. of the order of $\frac{\mu^2}{M_x}$, this leading to zero v.e.v. for the F-components of all superfields in 210, 210', $\mathcal{V}$. Therefore it is sufficient to find out the potential minimum connected with (3) with account of the mass terms of the superfields 126, $\overline{126}$ that are present in (5) and (6).

In the representations $(\overline{10},1,3)$ and (10,1,3) from 126 and $\overline{126}$ there are the singlets under the exact subgroup $SU(3)_c \times U(1)_{em}$; denote them by $\bar{R}$ and R, respectively; the similar singlets from (10,3,1) and $(\overline{10},3,1)$ we denote by L and $\bar{L}$. The minimum of potential $V = \sum_i |F_i|^2 + \frac{1}{2}\vec{\mathcal{D}}^2$ ($\vec{\mathcal{D}}$ is a vector of the adjoint representation SO(10)) is achieved at

$$\langle \bar{R} R \rangle = \frac{\alpha^2}{\alpha^2+\beta^2}\mu^2 \qquad \langle \bar{R} \rangle = \langle R \rangle$$

$$\alpha \langle X \rangle + \beta \langle y \rangle = M_3 - M + M' \qquad \langle \bar{L} \rangle = \langle L \rangle = 0 \qquad (7)$$

$$\langle z \rangle = 0 \quad , \quad \langle t \rangle = 0$$

where M and M' are connected with v.e.v. of superfields $(1,1,1)_{210}$ and $(15,1,1)_{210'}$, respectively; the condition $\langle \bar{R} \rangle = \langle R \rangle$ provides the absence of the $\mathcal{D}$ -term.

Due to nonzero values of $\langle \bar{R} \rangle$, $\langle R \rangle$ the intermediate symmetry $SU(3)_c \times U(1) \times SU(2)_L \times SU(2)_R$ is broken up to G_0 . Besides, the supersymmetry is broken as well. Indeed,

$$V_{min} = \langle \left|\frac{\partial W}{\partial x}\right|^2 \rangle + \langle \left|\frac{\partial W}{\partial y}\right|^2 \rangle = \frac{\alpha^2\beta^2}{\alpha^2+\beta^2}\mu^4 > 0 \qquad (8)$$

If instead of superfields X , y one determines the superfields

$x'=(\alpha X+\beta y)/\sqrt{\alpha^2+\beta^2}$ and $y'=(\alpha y-\beta X)/\sqrt{\alpha^2+\beta^2}$, then we have $\langle F_{x'}\rangle = 0$, $\langle F_{y'}\rangle = \alpha\beta\mu^2/\sqrt{\alpha^2+\beta^2}$, i.e. the fermionic component y' is the Goldstone fermion, while $\langle y'\rangle$ is not determined [1].

The supersymmetry breakdown parameter can be defined as $\Delta = \frac{\alpha\gamma\beta^2}{\alpha^2+\beta^2}\mu^2$ [2]. One can readily see that at a tree level the mass splitting between superpartners of the order of Δ arises only for superfields z, t since 126, $\overline{126}$ do not interact with the superfield y' whose F-component has nonzero v.e.v..

One can see from (7) that all particles from 126 + $\overline{126}$ (except for the $SU(3)_c$ singlets from ($\overline{10}$,1,3) + (10,1,3) connected with the intermediate symmetry breakdown) obtain a superlarge mass $\sim M_x$ according to the survival hypothesis for the Higgs fields [9].

However one can readily see that the equations for the potential minimum have along with the solution (7) also the following one:

$$\langle \bar{L} L\rangle = \frac{\alpha^2}{\alpha^2+\beta^2}\mu^2 \qquad \langle \bar{L}\rangle = \langle L\rangle$$

$$\sqrt{\alpha^2+\beta^2}\langle X'\rangle = M_3 + M + M' \qquad \langle \bar{R}\rangle = \langle R\rangle = 0 \qquad (9)$$

$$\langle z\rangle = 0\,, \qquad \langle t\rangle = 0$$

For this solution the intermediate symmetry is broken up to $SU(3)_c$ x x $SU(2)_R$ x $U(1)$, i.e. the SU(2) left group is broken prior to the right one, while the W-bosons obtain a mass of the order of $\mu \gg M_W$. what is quite inacceptable. Note that the value of the potential minimum for the (9) solution is the same as for the (7) one: $\frac{\alpha^2\beta^2}{\alpha^2+\beta^2}\mu^4$. This implies that at a tree level it is impossible to exclude this possibility or discriminate it from the physical one when according to the (7) solution the SU(2) right group is broken at $\mu \gg M_W$ and the left group at M_W.

These two possibilities can be discriminated owing to the fact that simultaneously with the intermediate symmetry also the supersymmetry is broken. Then the quantum corrections to the vacuum energy which are nonzero only at broken supersymmetry can lead to the situation when the physically acceptable minimum lies lower than the nonphysical one.

The first non-vanishing quantum correction to the vacuum energy appears owing to a superdiagram of Fig.1, where along the loop the superfield Z passes. The contributions to the vacuum energy of this diagram differ for the cases of (7) and (9). Thus, in the former case this contribution is $\sim\left(\frac{\gamma}{4\pi}\right)^2 \frac{\alpha^2 \Delta^2}{\alpha^2+\beta^2} \quad \frac{(M_3 - M + M')^2}{M_1^2}$, while in the latter one it is $\sim\left(\frac{\gamma}{4\pi}\right)^2 \frac{\alpha^2 \Delta^2}{\alpha^2+\beta^2} \quad \frac{(M_3 + M + M')^2}{M_1^2}$. If the initial parameters $M_3 + M'$ and M connected with the SO(10)-symmetry breakdown are of the same sign, then the contribution of this superdiagram to the vacuum energy for the solution of (7) will be less. Hence this condition having been satisfied, we have obtained a physically correct breakdown picture when at a scale μ the right SU(2) group is broken and not the left one, because the minimum corresponding to (7) will lie lower.

Note the following circumstance. The potential dependent of the superfields 210, 210' and responsible for the breakdown of SO(10) up to the intermediate symmetry has, in principle, also a minimum with $\langle 210' \rangle = 0$, $\langle (1.1.1.)_{210} \rangle \sim M_X$ corresponding to the breakdown of SO(10) up to G . However for this solution the quantum corrections owing to the same superdiagram of Fig.1 give a quantity $\sim\left(\frac{\gamma}{4\pi}\right)^2 \frac{\alpha^2 \Delta^2}{\alpha^2+\beta^2} \quad \frac{(M_3 - M)^2}{M_1^2}$ in case of (7). If M_3 and M' differ in signs, this correction will be larger than $\left(\frac{\gamma}{4\pi}\right)^2 \frac{\alpha^2 \Delta^2}{\alpha^2+\beta^2} \quad \frac{(M_3 - M + M')^2}{M_1^2}$, this corresponding to the fact that a minimum with the intermediate symmetry G_1 will lie lower. i.e.

a physically more acceptable breakdown version where the problems with the 210-plet masses and proton decay are absent is realized.

In our model one can easily calculate from the renormalization group equations the dependence of the breakdown scales for SO(10), M_X, and for the intermediate symmetry G_1, M_R ($M_R \sim \alpha\mu / \sqrt{\alpha^2+\beta^2}$), on the Weinberg angle [6]. The result is shown in Fig.2. The intersection of the curves referring to the dependence M_X and M_R on $\sin^2\theta_W$ corresponds to the results of the supersymmetric SU(5) model. One can see that in the vicinity of the experimental value $\sin^2\theta_W = 0.226$ the values $M_R \sim 10^{11} - 10^{12}$ GeV, this being in good agreement with the estimation for the parameter Δ given in [2]: $\Delta \sim (10^9 - 10^{11}\ \mathrm{GeV})^2$.

As to the low-energy sector, note that in our model, just like in Refs [2,3,12], the splitting of the ordinary particle supermultiplets. along with the $SU(2)_L \times U(1)_Y$ -breakdown, must arise owing to the quantum corrections. Here we have two possibilities. A first one implies adding the term of interaction between 126-plets and superfield Z, $\overline{126}\ 126\ Z$, to the superpotential. Then the nonzero contribution to the mass of the scalar partners of ordinary fermions arises only in the third loop. A second possibility is to replace the singlet superfields Z, t by the SO(10) 10-plets or 45-plets. Then, just like in [2], the scalar fermion masses occur in the second loop. These aspects will be considered in detail elsewhere. Note only that like in [13], the triplet-doublet splitting arises owing to the coupling λ 126 10 210: though the presence of the v.e.v. in 126 leads to occurence of mass also for doublet, it is however of the order of $\frac{\alpha^2}{\alpha^2+\beta^2}\frac{\lambda^2\mu^2}{M^2}$ and can be of the order of M_W for a sufficiently large range of parameters.

Note in conclusion that the possibility of simultaneous breakdown of supersymmetry and intermediate symmetry was considered in [11], but unlike our work, wherein we consider a spontaneous breakdown of supersymmetry, in [11] the supersymmetry is broken by means of directly introduced mass terms.

Thus we suggest a scheme of simultaneous breakdown of intermediate symmetry $SO(10) \to SU(3)_c \times U(1) \times SU(2)_L \times SU(2)_R$ and supersymmetry by means of a single scale parameter. This intermediate symmetry, which is preferable physically, owing to the broken supersymmetry has a minimum lying lower than $SU(4) \times SU(2)_L \times SU(2)_R$. The intermediate symmetry is broken by the v.e.v. of the Higgs superfields $\underline{126} + \overline{126}$. Owing to the quantum corrections the potential minimum turns out to correspond to breakdown of the intermediate symmetry up to the standard group $SU(3)_c \times SU(2)_L \times U(1)_y$. The value of the Weinberg angle is less than that in the supersymmetric SU(5) model and agrees with the experiment.

The authors are thankful to E.Sh. Egoryan, S.G. Matinyan, R.L. Mkrtchyan and A.G. Sedrakyan for the useful discussions.

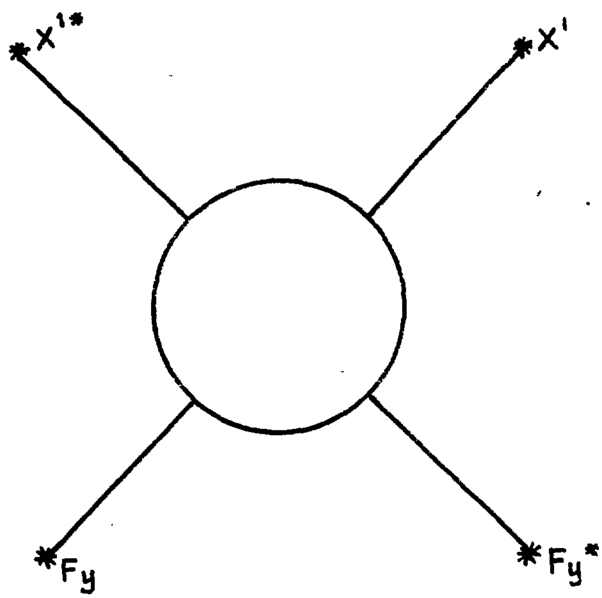

Fig. 1. A superdiagram that contributes to the vacuum energy.

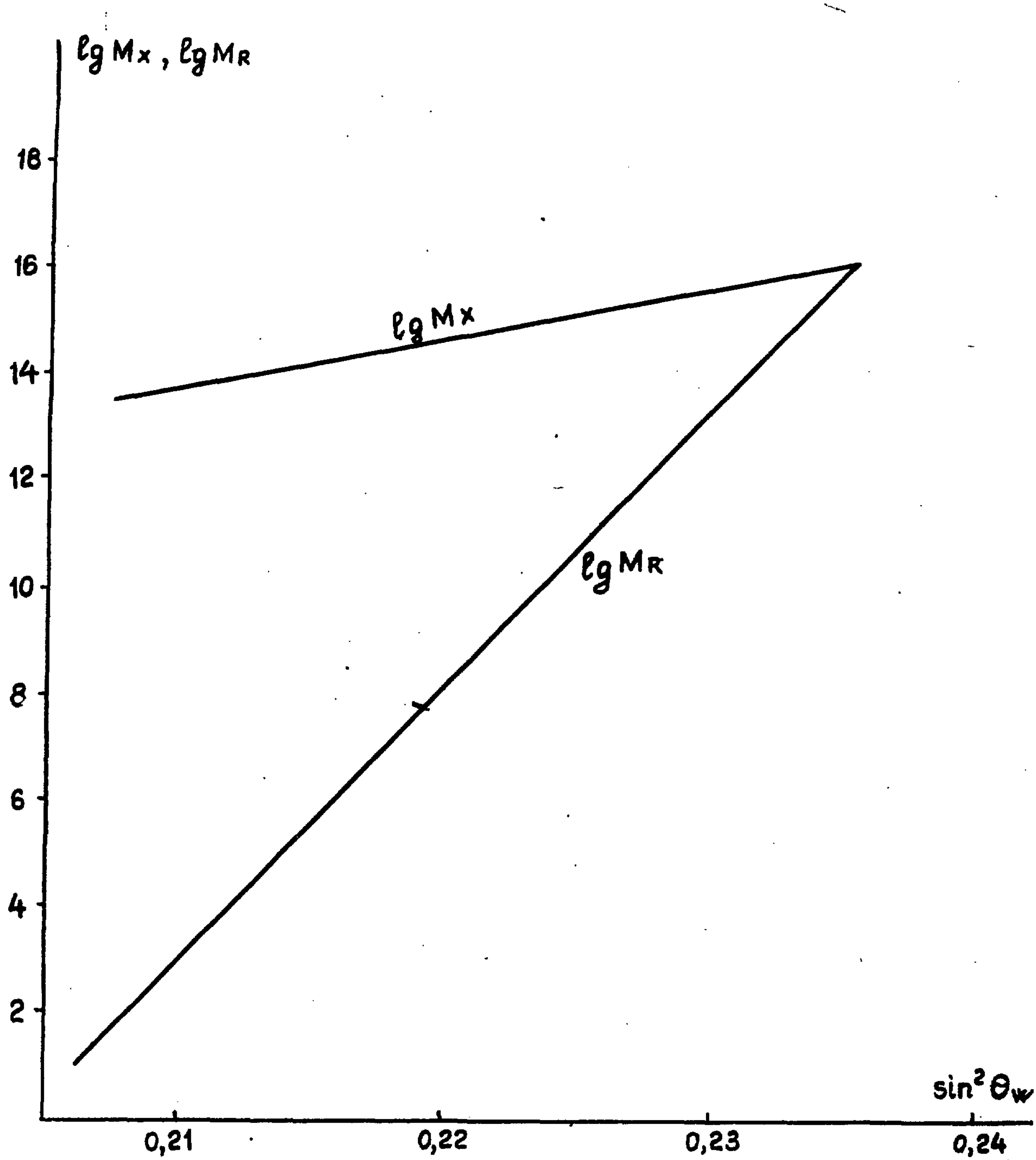

Fig. 2. M_X and M_R as functions of the Weinberg angle $\sin^2\theta_W$ for the quantum chromodynamics parameter Λ = 0.15 GeV.

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The manuscript was received 17 May 1985

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НАРУШЕНИЕ СУПЕРСИММЕТРИИИ И ПРОМЕЖУТОЧНОЙ СИММЕТРИИ
В ТЕОРИИ СУПЕРОБЪЕДИНЕНИЯ SO(IO)

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

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

Подписано в печать I2/УШ-85г. ВФ-08945 Формат 60x84/I6
Офсетная печать. Уч.изд.л. I,0 Тираж 299 экз. Ц.I5 к.
Зак.тип.№ 386 Индекс 3624

Отпечатано в Ереванском физическом институте
Ереван 36, Маркаряна 2

117

индекс 3624

ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ