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NEUTRAL FERMIONS IN SUPERSTRING E_6-MODEL

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INTRODUCTION

It is widely believed that superstrings can provide a consistent quantum theory of all fundamental interactions, including gravitation. Noticeable progress is made in this field and some definite contours of a future theory are already outlined. Now it seems that the most realistic scheme is the $E_8 \times E_8$ heterotic string theory in ten dimensions [1].

An effective four-dimensional theory can be obtained from a ten-dimensional one by compactification on the Calabi-Yau manifold [2]. In this case the gauge group $E_8 \times E_8$ is reduced down to $E_8 \times E_6$, $E_8 \times SO_{10}$ or $E_8 \times SU_5$ [3,4] and N = 1 supersymmetry is conserved.

All observed particles belong to the singlet representation of the unbroken E_8-gauge group. Threfore its gauge fields interact with observable particles by means of gravitation alone and form a dark sector of matter. This leads to the four-dimensional N = 1 supersymmetric theory with E_6 or SO_{10}, SU_5 gauge groups. We will consider the theory with the E_6-gauge group. This group was earlier considered as a basis of the old Grand Unified model. The superstring version of the E_6-model differs in many aspects from such approach to unification; it has a more regid frame. For example, chiral superfields only belong to the following E_6-multiplets [2]

$$n_f 27 + b_{1,1}(27_H + \overline{27}_H) + 1, \tag{1}$$

where $n_f = \chi/2$ is the number of a particle generations, χ and $b_{1,1}$ are the Euler characteristic and the Betti-Hodge number of the Calabi-Yau manifold.

A physically acceptable picture below the compactification scale can be obtained if the compact manifold is non-simply connected. Usually, one considers quotient manifolds $K = K_0/G$, where K_0 is the simply connected manifold and G is its freely acting discrete symmetry group. The Euler characteristic of K is $\chi(K) = \chi(K_0)/n(G)$. $n(G)$ being the number of elements of G.

This is very important, since values of χ for the well-known simply connected Calabi-Yau manifolds are too large

(≥ 100), which leads to an unacceptably large number of generations.

Compactification on multiply connected manifolds provides a new type of gauge symmetry breaking - flux breaking caused by topologically nontrivial configurations of gauge fields [3].

Topology of the compact manifold K determines many other important properties of the 4-dimensional theory. Only some of these properties have been studied now and they make superstring phenomenology rather restrictive.

Some questions arise: does this scheme describe the well-known experimental and cosmological facts? Is it possible to solve problems which are not solved in Standard Model and in Grand Unified models? Now many papers are devoted to these questions [5-10].

Neutrino mass problem is one of the most complicated problems for superstring inspired models. In particular, it is difficult to bring weak universality into line with the small neutrino mass. A well-known "see-saw" mechanism [11,12] is invalid in this case [9]. There are some approaches to this problem:

1. to take into account non-renormalizable terms like [13] $\frac{1}{M_C} 27 \times 27 \times \overline{27}_H \times \overline{27}_H$,
2. to use neutral gaugino, corresponsing to B-L-symmetry to form $\Delta(B-L)=1$ Dirac mass term [14],
3. to take into account the Yukawa interactions with the E_6- singlet field [15,16] $r \cdot 27 \times \overline{27}_H \times 1$,
4. to generate the neutrino mass in a high order of perturbation theory [17].

The problem of an additional neutral lepton is in close relation with the neutrino mass problem. During the last years such leptons have been searched for at various experimental facilities [18]. In this paper we consider the neutrino mass problem and a possibility of existence of an additional light neutral lepton within the framework of the superstring inspired E_6-model with the intermediate energy scale. Our approach differs from the above-mentioned one by a maximum wide sector of neutral fields for one generation. The non-renormalizable terms and E_6-singlet fields are not used.

It is shown that the mass matrix of neutral fermions consistent with weak universality does not exclude existence of an additional neutral lepton with a mass of tens or hundreds MeV.

Neutrino appears to be a Majorana particle with a mass close to zero. More exact quantitative estimation of these masses is very difficult because of large uncertainties produced by compactification of the ten-dimensional theory.

We neglect the mixing of neutral fermions which belong to different generations. To take it into account is very difficult from the technical point of view. On the other hand, no unambiguous prediction of this effects from superstring is known.

The paper is organized as follows.

Section 1 is devoted to some aspects of superstring phenomenology. The mass term of the initial Lagrangian is discussed in Sect.2. The mass spectrum of neutral particles has been obtained by means of diagonalization of the mass matrix.

Some possibilities of experimental observation of neutral fermions are considered in Sect.3.

1. HIERARCHY OF SYMMETRIES AND SET OF FIELDS

Let us consider some questions of superstring phenomenology ditectrly related to determining the mass matrix of neutral fermions.

An important part of superstring models is topological symmetry breaking at the compactification scale M_C. This effect is due to topologically non-trivial vacuum configurations of gauge fields A_m on the multiply connected manifold $K = K_0/G$. It is the subgroup $\mathcal{G} \subset E_6$ satisfying the condition [12]

$$[\mathcal{G}, U_g] = 0, \tag{2}$$

where

$$U_g = P \exp\{i \oint A_m dx^m\}, \quad g \in G \tag{3}$$

that remains unbroken.

The condition Fmn = 0 is fulfilled for fields A_m. Integration was carried out over the loops on K which are not contractable to a points.

If G is an Abelian group, $\mathcal{G}$ has the rank 6; if it is non-Abelian, the rank is 5 [4]. In this paper we consider a case with the subgroup of rank 6

$$E_6 \supset \mathcal{G} = SU_{3C} \times SU_{2L} \times SU_{2R} \times U_{1L} \times U_{1R}. \tag{4}$$

Here the electric charge operator has the form

$$Q = I_{3L} + I_{3R} + \frac{1}{2}(Y_L + Y_R).$$

The index theorem applied to the Dirac operator on the manifold K guarantees masslessness of all fields of $\overline{27}$-plets in formula (1) [14]. At the same time some 27_H and $\overline{27}_H$ fields get a large mass M_C due to topological symmetry breaking and decouple from the observed spectrum. The index theorem only demands that the remained light fidls should be present in combination $27_H + \overline{27}_H$. Then light components are usually regarded as Higgs fields; they ensure spontaneous breaking of the gauge group $\mathcal{G}$ according to the scheme.

$$\mathcal{G} \xrightarrow[M_I]{} SU_{3C} \times SU_{2L} \times U_{1Y} (\times U_{1\chi}) \xrightarrow[m_F]{} SU_{3C} \times U_1^{em}. \qquad (5)$$

Here $M_I \sim 10^{11}$ GeV and $m_F \sim 10^2$ GeV are the intermediate [20] and Fermi scales. $U_{1\chi}$ is the possible gauge extra factor.

From the point of view of the hierarchy problem supersymmetry breaking at the scale M_I is inadmissible. To preserve it below M_I, vacuum expectation values must comply with the following condition:

$$\langle 27_H \rangle = \langle \overline{27}_H \rangle.$$

It ensures that the D-term in the scalar potential is equal to zero.

Since this paper is aimed at considering the mass matrix of neutral fermions in the most general form we shall proceed from the maximum wide Higgs sector, which will include all electroneutral colourless fields of 27.

In order to determin the members of the 27-plet we show its $[SO_{10}, SU_5]$ contents [19]

$$27 = [16,10] + [16,\bar{5}] + [16,1] + [10,5] + [10,\bar{5}] + [1,1], \quad (6)$$

where

$$\begin{aligned}
&[16,10]; \quad (u,d) \equiv Q,\ U^c,\ e^+, \\
&[16,\bar{5}] : \quad (\nu, e^-) \equiv L,\ d^c, \\
&[16,1] : \quad \nu^c, \\
&[10,5] : \quad D,\ (N^c, E^+) \equiv E, \\
&[10,\bar{5}] : \quad D^c, (N, E^-) \equiv E^c, \\
&[1,1] : \quad S
\end{aligned} \qquad (7)$$

Here D is the exotic quark and E, E^C are the exotic lepton doublets.

We obtain a general form of the superpotential in the model under consideration

$$\begin{aligned}
P = {} & r_1 QQD + r_2 u^C d^C D^C + r_3 u^C D e^C + \\
& + \sum_{i,j,k} (r_1^{(i)} L_i E^C e^C + r_2^{(i)} Q u^C E_i + r_3^{(i)} Q d^C E_i^C + \\
& + r_4^{(i)} Q D^C L_i + r_1^{(ijk)} L_i E_j \nu_k^C + r_2^{(ijk)} E_i E_j^C S_k + \\
& + r_3^{(ijk)} d_i^C D_j \nu_k^C + r_4^{(ijk)} D_i D_j^C S_k).
\end{aligned} \qquad (8)$$

Summation is made over $i, j, k = (H,M) \equiv$ (fields of 27_H, fields of 27). The Higgs superfields are

$$\nu_H,\ \nu_H^C,\ N_H,\ N_H^C,\ S_H$$

and their mirror partners

$$\nu_H^*,\ \nu_H^{C*},\ N_H^*,\ N_H^{C*},\ S_H^*.$$

The scalar components of these superfields develop non-zero vacuum expection values and ensure symmetry breaking (5).

Quantum numbers for the subgroup $\mathcal{G} \supset E_6$ (see (4)) for all electroneutral fields of the model are listed in Table 1.

Table 1

Quantum numbers of neutral fermions from the 27-plet of E_6 *in the subgroup* $SU_{3C} \times SU_{2R} \times SU_{2L} \times U_{1L} \times U_{1R}$

Fields	I_{2L}	I_{2R}	Y_L	Y_R
ν	1/2	0	-1/3	-2/3
ν^C	0	-1/2	2/3	1/3
N	1/2	-1/2	-1/3	1/3
N^C	-1/2	1/2	-1/3	1/3
S	0	0	2/3	-2/3

2. MASS MATRIX OF NEUTRAL FERMIONS

In this paper we shall confine ourselves to consideration of the mass matrix within one generation.

In this case the model contains 14 neutral fermions which can mix with one another. They are in the following multiplets:

$$\nu,\ \nu^C,\ N,\ N^C, S \quad : \quad \text{27-plet of matter}$$

$$\nu_H, \nu_H^C, N_H, N_H^C, S_H : \quad \text{27-plet of higgsino} \tag{9}$$

$$\lambda^\circ_{2L}, \lambda^\circ_{2R}, \lambda_{1L}, \lambda_{1R} : \quad \text{78-plet of gaugino}$$

To obtain the mass matrix of these fields we shall proceed from the following mass term in Lagrangian of the model:

$$L_m = L(27^3) + L(27\times 78\times \overline{27}) + L(78^2)\,. \tag{10}$$

$L(27^3)$ can be determined from superpotential (8). It is a usual Yukawa contribution of the type $\psi\times\psi\times\langle H\rangle$, where ψ are the fermion fields from 27 and 27_H, H is the Higgs scalar.

The second and the third terms describe the gaugino interactions and soft supersymmetry breaking respectively. They have the form

$$\begin{aligned} L(27\times 78\times \overline{27}) = {} & \frac{1}{\sqrt{2}} g_{2L}\cdot\lambda^\circ_{2L}\cdot(\nu_H\langle\tilde\nu^*_H\rangle + \\ & + N_H\langle\tilde N^*_H\rangle - N^C_H\langle\tilde N^{C*}_H\rangle - \frac{1}{\sqrt{2}} g_{2R}\lambda^\circ_{2R}(\nu^C_H\langle\tilde\nu^{C*}_H\rangle + \\ & + N_H\langle\tilde N^*_H\rangle - N^C_H\langle\tilde N^{C*}_H\rangle) + \\ & + \sqrt{2}\, g_{1L}\lambda_{1L}\cdot(-\frac{1}{3}\nu_H\langle\tilde\nu^*_H\rangle + \frac{2}{3}\nu^C_H\langle\tilde\nu^{C*}_H\rangle - \\ & - \frac{1}{3}N_H\langle\tilde N^*_H\rangle - \frac{1}{3}N^C_H\langle\tilde N^{C*}_H\rangle + \frac{2}{3}S_H\langle\tilde S^*_H\rangle) + \\ & + \sqrt{2}\, g_{1R}\cdot\lambda_{1R}\cdot(-\frac{2}{3}\nu_H\langle\tilde\nu^*_H\rangle + \frac{1}{3}\nu^C_H\langle\tilde\nu^{C*}_H\rangle + \\ & + \frac{1}{3}N_H\langle\tilde N^*_H\rangle + \frac{1}{3}N^C_H\cdot\langle\tilde N^{C*}_H\rangle - \frac{2}{3}S_H\langle\tilde S^*_H\rangle)\,, \end{aligned} \tag{11}$$

$$L(78^2) = G^{(1)}\lambda^\circ_{2L}\cdot\lambda^\circ_{2L} + G^{(2)}\lambda^\circ_{2R}\cdot\lambda^\circ_{2R} + G^{(3)}\lambda_{1L}\cdot\lambda_{1L} + G^{(4)}\lambda_{1R}\lambda_{1R}\,. \tag{12}$$

The mass matrix of the neutral fermions can be obtained from these formulae. To get information on the mass spectrum one should estimate matrix elements. Since SU_{2L}-singlet Higgs fields break symmetry at the scale M_I, we shall consider that

$$r\langle\tilde\nu^C_H\rangle \approx r\langle\tilde S_H\rangle \approx M_I \approx 10^{11}\,\text{GeV}. \tag{13}$$

The vacuum expectation values and Yukawa coupling constants which correpond to SU_{2L}-doublet Higgs fields breaking symmetry at the Fermi scale can be estimated on the basis of mass formulae for the Z-bozon and the u-quark

$$M_Z \approx Z \equiv g_{2L}\langle\tilde N^C_H\rangle \approx 10^2\ \text{GeV}, \tag{14}$$

$$m_u \approx m \equiv r\langle\tilde N^C_H\rangle \approx 10^{-2}\ \text{GeV}. \tag{15}$$

For the further calculation of the spectrum we shall admit the following

$$r_i \approx r,\quad g_{2R}\approx g_{2L}\approx g_{1L}\approx g_{1R}\approx g,\qquad G^{(i)}\approx G\,,$$

$$r\langle\tilde\nu_H\rangle \approx r\langle\tilde N_H\rangle \approx r\langle\tilde N^C_H\rangle \approx m \approx 10^{-2}\ \text{GeV},$$

$$g\langle\tilde\nu_H\rangle \approx g\langle\tilde N_H\rangle \approx g\langle\tilde N^C_H\rangle \approx Z \approx 10^2\ \text{GeV},$$

$$g\langle\tilde\nu^C_H\rangle \approx g\langle\tilde S_H\rangle \approx A \equiv \frac{g}{r}M_I \approx 10^{15}\,\text{GeV}.$$

The last relation is obtained from (13) with allowance for (14) and (15). The mass matrix obtained from (8), (11), (12) in this approximation coinsides with the matrix written in Table 2 at $\beta=\alpha=1$. The meaning of α and β will be clear a bit later.

The mass spectrum of neutral fermions corresponds to eigenvalues of this matrix, i.e. to solutions of the equation

$$\det|\hat M - \lambda\hat I| = 0\,. \tag{17}$$

It is obvious that the neutrino should be searched for among the eigen-vectors with zero eigenvalues (or those close to zero). The matrix under consideration has a high degree of symmetry, which is manifested in equality of different matrix elements. This symmetry is however an approximate one. Its

Table 2.

Elements of the mass matrix $\mathcal{M}$ *of neutral fermions. The table lists non-zero matrix elements above main diagonal*

(i,j)	$\hat{\mathcal{M}}_{ij}$	(i,j)	$\hat{\mathcal{M}}_{ij}$	(i,j)	$\hat{\mathcal{M}}_{ij}$	(i,j)	$\hat{\mathcal{M}}_{ij}$
ν, ν^c	αm	N^c, S	m	ν_H, λ_{1L}	$-Z/3$	N_H^c, S_H	m
ν, N^c	$\alpha^{-1}\mathcal{M}$	N^c, ν_H	$\mathcal{M}$	ν_H^c, N_H^c	m	N_H^c, λ_{2R}	$Z/2$
ν, ν_H^c	αm	N^c, ν_H^c	m	ν_H^c, λ_{2R}	$-A/2$	N_H^c, λ_{2L}	$-Z/2$
ν, N_H^c	$\alpha^{-1}\mathcal{M}$	N^c, N_H	$\mathcal{M}$	$\nu_H^c \lambda_{1R}$	$A/3$	N_H^c, λ_{1R}	$Z/3$
ν^c, N^c	αm	N^c, S_H	m	ν_H^c, λ_{1L}	$2A/3$	N_H^c, λ_{1L}	$-Z/3$
ν^c, ν_H	m	S, N_H	m	N_H, N_H^c	$\mathcal{M}$	S_H, λ_{1R}	$-2A/3$
ν^c, N_H^c	m	S, N_H^c	m	N_H, S_H	m	S_H, λ_{1L}	$2A/3$
N, N^c	$\mathcal{M}$	ν_H, ν_H^c	m	N_H, λ_{2R}	$-Z/2$	$\lambda_{1R}, \lambda_{1R}$	G
N, S	m	ν_H, N_H^c	$\mathcal{M}$	N_H, λ_{2L}	$Z/2$	$\lambda_{1L}, \lambda_{1L}$	G
N, N_H^c	$\mathcal{M}$	ν_H, λ_{2L}	$Z/2$	N_H, λ_{1R}	$Z/3$	$\lambda_{2R}, \lambda_{2R}$	G
N, S_H	m	ν_H, λ_{1R}	$-2Z/3$	N_H, λ_{1L}	$-Z\beta/3$	$\lambda_{2L}, \lambda_{2L}$	G

accuracy does not exceed the accuracy of approximations (16). As a consequence of the symmetry, the mass matrix has two zero eigenvalues. The corresponding two-dimensional subspace of eigenvectors $\vec{X}$ is characterised by the relation $X_1 = X_8 = X_9 = c$. This follows from the solution of the set of equations

$$(\hat{M} - \lambda^{(i)}\hat{I})\vec{X}^{(i)} = 0, \quad |\vec{X}^{(i)}|^2 = 1, \quad i = 1, 2, \ldots, 14. \tag{18}$$

Therefore physical massless fields have the form

$$\nu^{Ph.} = X_k \ell_k^{\circ} = c\nu + c\nu_H + cN_H^C + \ldots, \tag{19}$$

where

$$\ell_k^{\circ} = (\nu, \nu^C, N, N^C, S, \nu_H, \nu_H^C, N_H, N_H^C, S_H, \lambda_{2L}^{\circ}, \lambda_{2R}^{\circ}, \lambda_{1L}, \lambda_{1R}) \tag{20}$$

are current fields.

At the same time universality of weak interactions [21] and experimental data on the matrix element of neutrino mixing with neutral leptons [18]

$$|U_{\nu n}|^2 \lesssim 10^{-8} \tag{21}$$

imposes limits on states corresponding to the neutrino

$$X_1 \equiv 1 - \frac{1}{2}|U_{\nu n}|^2 \gtrsim 1 - 10^{-8}, \quad \sum_{k=2} X_k^2 \equiv |U_{\nu n}|^2 \lesssim 10^{-8}. \tag{22}$$

These conditions cannot be fulfilled for fields (19). This means that the above-mentioned approximate symmetry of the mass matrix is broken. The breakdown must ensure at least fulfillment of conditions (22). Let us introduce the parameter $\alpha \approx 10^3$ in matrix. Then, as the solution of equations (18) shows, conditions (22) will be fulfilled for each of the two massless states which are still present in the spectrum. Each state can be regarded as a neutrino.

However, there is only one neutrino per generation. Therefore one must eliminate degeneration of the zero mass level, so that only one massless state satisfying (22) remained. The minimal complication of mass matrix leading to the necessary result is to introduce the parameter $\beta \neq 1$ (Table 2).

Thus we obtain a mass matrix yielding one massless neutrino. Its masslessness is the result of approximations (16). This implies a conclusion that the model under consideration allows a light, perhaps massless, neutrino. More accurate calculations of its mass are possible after refining the values of matrix elements. It is a separate problem which is not solved yet because of its diffeculty.

Solution of the equation (17) for mass matrix leads to the following mass spectrum of neutral fermions

$$\begin{aligned} &m_\nu = m^{(1)} \approx 0, \quad m^{(2)} \approx -2(m^2/M) \approx 10^{-6}\ \text{eV}, \\ &m_n = m^{(3)} \approx m(1-\beta)\sigma \approx m \approx 10^{-2}\ \text{GeV}, \quad m^{(4)} \approx Z \approx 10^2\ \text{GeV}, \\ &m^{(5,6)} \approx \pm\alpha m\xi \approx \pm\alpha m \approx 10^2\ \text{GeV}, \quad m^{(7,8)} \approx \frac{1}{2}\left(G \pm \sqrt{G^2 + \frac{2}{3}Z^2\alpha^2}\right) \\ &m^{(9,10)} \approx \pm\frac{1}{2}G \approx 10^3\ \text{GeV}, \quad m^{(11,12)} \approx \pm M \approx \pm 10^{11}\ \text{GeV}, \\ &m^{(13,14)} \approx \pm A \approx \pm 10^{15}\ \text{GeV}, \end{aligned} \tag{23}$$

where

$$\sigma = [(\alpha^2+3)\,\alpha^2/(3\alpha^2(\alpha^2+4)+5-\beta(3+\alpha^2)+\beta^2(1+\alpha^2))]^{1/2} ,$$

$$\xi = [2\alpha^2(\alpha^2+3)/(4\alpha^4+7\alpha^2+1)]^{1/2}/\sigma .$$

As is seen, fields with masses m_ν, $m^{(2)}$, $m^{(3)}$, $m^{(4)}$ are Majorana fields; others are Dirac fields.

Physical fields

$$\ell_k^{Ph.} = (\nu^{Ph.}, \chi, n, n_1, \dots, n_{11}) \qquad (24)$$

with these masses are related to original current fields (20) via the formula

$$\ell_k^{Ph.} = \hat{U}_{ki}\,\ell_i^{o} , \qquad \hat{U}_{ik} = X_k^{(i)} , \qquad (25)$$

where $\hat{U}$ is the mixing obtained by solving set of equations (18). Because of its complication we do not write down this matrix, but present only those physical fields, which are interesting from the physical point of view.

It follows from (23) and (25) that the spectrum contains two light states with a significant admixture of SU_{2L}-doublet current fields

$$\nu^{Ph.} \approx (1-\frac{1}{2}\alpha^{-2})\nu - \alpha^{-1}(\nu_H + N - N_H + N_H^C - N_H^C) , \qquad (26)$$

$$n \approx p_1\alpha^{-2}\nu - p_2(1-\frac{1}{2}\alpha^{-2})N_H + \dots . \qquad (27)$$

$\nu^{Ph.}$ – the Majorana neutrino with a mass close to zero; n – the light neutral lepton whose mass m_n can be very small. In formulae (27) an insignificant admixture of the Standard group singlet fields is not written.

Besides, spectrum (23) contains a very light fermion χ of the mass 10^{-5} eV which is sterile under standard group

$$\chi = (\nu^c + S)/\sqrt{2}. \qquad (28)$$

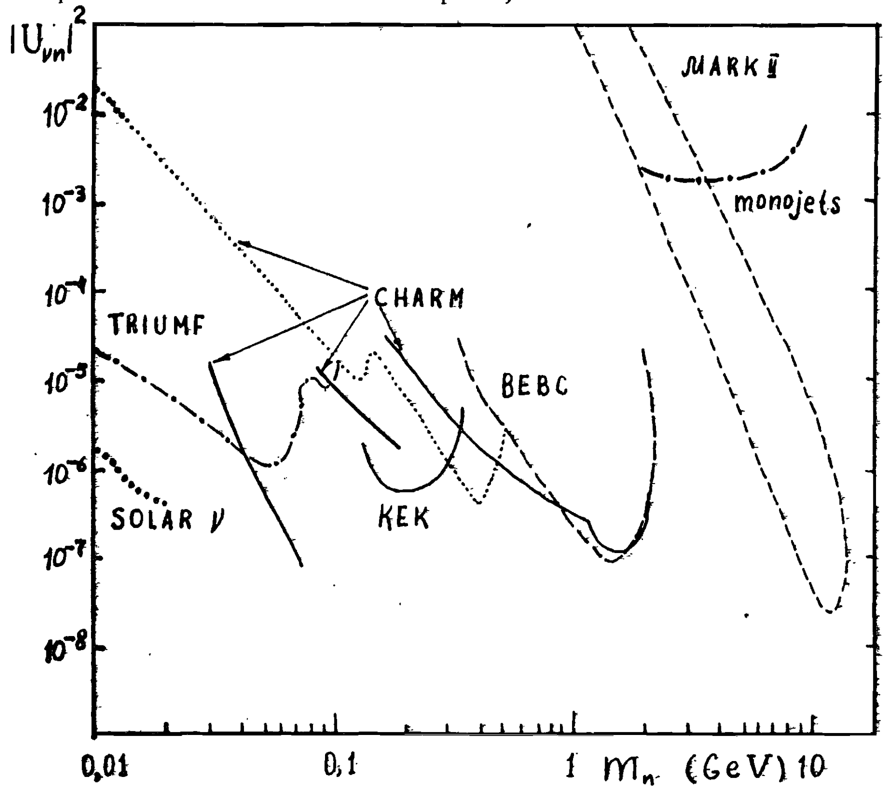
There are a few comments on solution method for equations (17), (18). Coefficients of the polynomial to the 14-th power of corresponding to the left-hand side of equation (17) were computed in an analytical form. Then the equation was solved with an accuracy to the leading order of the perturbation theory in the small parameter m/M. System (18) is solved in the same approximation. The obtained solution of (17), (18) does not

qualitatively change when values of parameters α, β, M, m, Z vary within three orders.

3. ON A POSSIBILITY OF EXPERIMENTAL OBSERVATION OF NEUTRAL LEPTONS

Thus, beside the almost massless neutrino, other quite light neutral leptons can be found in each generation of fermions. The model under consideration admits of masses which allow direct experimental observation of these particles. Lepton n (27) is of special interest from this point of view, since it can contain a noticeable admixture of the SU_{2L}-doublet field, and consequently, it must participate in weak interactions. Weak vertices get the corresponding factors $|U_{\nu n}|$ (see (26)-(27)).

The Figure shows up-to-date result obtained in studying the problem of the neutral lepton;



Experimental limits on neutral lepton mass m_n *and square matrix element* $|U_{\nu n}|^2$.

The main sources of neutral leptons (also called "heavy netrinos") are the following processes:

- in experiments with wide-band neutrino beams:

$$K^+ \to e^+ n, \qquad (29)$$

$$\nu N \to n X \ \text{(hadrons)} \qquad (30)$$

- in "beam-dump" experiments:

$$D^+ \to e^+ n. \qquad (31)$$

The neutral lepton n produced in these reactions decays by one of the modes given below:

$$n \to e^+ e^- \nu_e, \quad e^+ \mu^- \nu_e, \quad e^- \mu^+ \nu_\mu, \quad \mu^+ \mu^- \nu_\mu, \quad e^- \pi^+, \quad \mu^- \pi^+. \qquad (32)$$

The width of each of the above leptonic decay modes is equal to

$$\Gamma_{\ell\ell\nu} = \frac{G_F^2}{192\pi^3} m^5 |U_{\nu n}|^2, \qquad (33)$$

The width of respective semileptonic decays is

$$\Gamma_{\ell\pi} = \frac{G_F}{16\pi} \cos\theta_c \cdot f_\pi \cdot m_n \cdot |U_{\nu n}|^2, \qquad (34)$$

where $f_\pi \approx 137$ MeV, $\cos\theta_c \approx 0.98$. Formulae (33), (34) do not take into account masses of final particles. Study of reaction (29) allows investigation of the neutral lepton mass region $m_n \lesssim 493.669$ MeV. This limit is shiffed to 1868.4 MeV in reaction (31). Experimental statistics in the mass region $m_K \lesssim m_n \lesssim m_D$ is determined by the value of the production cross section for charmed particles which increases with the energy of incident protons. In some models [22] the value of the cross section increases by two orders with the proton beam energy growing from 70 GeV to 3 TeV. Larger statistics leads to a wider region of measurements (see the Figure) with respect to smaller values of $|U|$. The limitation $m_n \lesssim 1868.4$ MeV remains valid for reaction (31).

This limit for m_n can be made higher by studying the reaction of neutral lepton production in deep inelastic scattering of neutrino on the nucleon (30). One must detect production and decay of n. Semileptonic modes $n \to eX$ (hadrons), μX (hadrons) are the most preferable.

The expected number of decays N of neutral leptons in the fiducial volume of the detector can be computed according to the expression

$$N = \int a \cdot f(m_n, |U|) \log\left(\frac{E}{m_n}\right) \cdot \phi(E)\, dE, \qquad (35)$$

where a is the parameter characterising the detector, f is the known function of m_n and $|U|$; $\phi(E)$ is the spectrum of the neutrino beam.

Thus, the increasing mean energy of the beam results in a greater number of the events.

CONCLUSION

So the superstring E_6 model with the intermediate scale of symmetry breaking allows a light, probably massless Majorana netrino ν and a light neutral lepton n. The lepton n (30) participates in weak interactions and can be experimentally observed. We have discussed some conditions under which these observations can be performed or are already performed at some facilities [18].

It goes without saying that our result is not a strict prediction of the superstring theory. It only indicates a possible existence of the particles mentioned. A more accurate solution of this problem depends upon a choise of the Calabi-Yau manifold. The theory is still unable to say what manifold shoud be.

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Алтайский М.В., Исаев П.С., Коваленко С.Г. E2-87-519

Нейтральные фермионы в суперструнной E_6-модели

Изучен спектр нейтральных фермионов в пределах одного поколения киральных суперполей суперструнной E_6-модели. В качестве промежуточной группы, выживающей при топологическом нарушении симметрии, рассмотрена подгруппа $SU_{3C} \times SU_{2L} \times SU_{2R} \times U_L(1) \times U_R(1) \subset E_6$. На промежуточном масштабе 10^{11} ГэВ происходит ее спонтанное нарушение до стандартной группы. Согласование массовой матрицы с принципом универсальности слабых взаимодействий указывает на возможность существования в модели, помимо легкого майорановского нейтрино, легкого нейтрального лептона. Его масса может лежать в области кварковых масс, т.е. составлять десятки или сотни МэВ.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Altaiskij M.V., Isaev P.S., Kovalenko S.G. E2-87-519

Neutral Fermions in Superstring E_6-Model

The mass spectrum of neutral fermion has been studied within the framework of the superstring inspired E_6-model. The subgroup $SU_{3C} \times SU_{2L} \times SU_{2R} \times U_L(1) \times U_R(1) \subset E_6$ is considered as an intermediate gauge group surviving after flux breaking. At the intermediate energy scale $\sim 10^{11}$ GeV it is spontaneously broken. The obtained mass matrix is consistent with weak universality and allows existence of a light, possibly massless, Majorana neutrino and an additional neutral lepton in the spectrum. The mass of the lepton can be in the region of quark masses.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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