Supersymmetry breaking in superstring theories

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(Submitted 24 September 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **44**, No. 9, 416–418 (10 November 1986)

A mechanism is proposed for breaking of the supersymmetry in a low-energy $d = 4$ supersymmetry theory found as the low-energy limit of a ten-dimensional superstring theory.

The ten-dimensional superstring theory with the gauge group $E_8 \times E_6$, which is the first realistic example of a theory that unifies all interactions known in nature, has recently been studied extensively.[1–6] Upon compactification of the ten dimensional theory on a manifold of the Kalabi-Yau type, the effective four-dimensional theory will have a $N = 1$ supersymmetry and will be described by the $E_8 \times E_6$ gauge group.[3] An effective four-dimensional Lagrangian, which describes $N = 1$ supergravity with a Kähler protential of the type

$$G = -\ln(S + S^+) - 3\ln(T + T^+ - 2|C|^2) + \ln|W(C)|^2, \tag{1}$$

$$W(C) = d_{xyz} C_x C_y C_z$$

 0021-3640/86/210535-03$01.00

was obtained by the dimensional-reduction method.[4,5] Here S and T are scalar fields which are singlets with respect to the gauge group $E_8 \times E_6$, and C_x are fields which transform in accordance with the $\underline{27}$ or $\overline{\underline{27}}$ representations with respect to the E_6 gauge group. The effective potential corresponding to the Kähler potential (1) is[4,5]

$$V = \frac{1}{(S+S^+)(t+t^+)} \left(|W|^2 + \frac{t+t^+}{6} |W'_C|^2 \right) + D^2 - \text{terms}, \tag{2}$$

$$t = T - |C_x|^2 .$$

In a $N=1$ real world, the supersymmetry should be broken. It was suggested in Refs. 6 and 7 that a gluino condensate of the E_8 gauge group (or of one of its subgroups) should be used to break $N=1$ supersymmetry. The use of gluino condensate accounts for the appearance in the effective potential W of an increment of the type[6]

$$\Delta W = h \exp\left(-\frac{3S}{2b_0}\right), \quad b_0 > 0.$$

Incorporation of the increment ΔW leads to a replacement of the term $|W|^2$ in expression (2) by[6]

$$\left| W + h\left(\frac{3S_R}{b_0} + 1\right) \exp\left(-\frac{3S}{2b_0}\right)\right|^2, \quad S_R = \mathrm{Re}\, S. \tag{3}$$

As can be seen from expression (3), at $W=0$ there is no minimum with zero vacuum energy density (the parameter S_R varies between zero and $+\infty$).

In this letter we show that breaking of the E_8 gauge group to the $G_1 \times G_2$ group (a symmetry breaking of this sort can be brought about by means of the Hosotani[8] mechanism) because of the nonzero gluino condensates of the G_1 and G_2 groups results in the breaking of the $N=1$ supersymmetry. For definiteness, we consider the case $G_1 = \mathrm{SU}(2)$, $G_2 = \mathrm{SU}(3)$. Allowance for the gluino condensate leads to the appearance of an increment in the effective potential

$$\Delta W = h_2 \exp\left(-\frac{3S}{2b_2}\right) \exp(i\pi k_2) + h_3 \exp\left(-\frac{3S}{2b_3}\right) \exp\left(\frac{2\pi i k_3}{3}\right),$$

$$b_N = \frac{3N}{16\pi^2}; \quad k_2 = 1, 2; \quad k_3 = 1, 2, 3. \tag{4}$$

The parameters h_2 and h_3 are generally of the same order of magnitude. For simplicity, we consider the case $h_2 = h_3$. Allowance for increment (4) results in the replacement of the term $|W|^2$ in expression (2) by

$$\left| W + h_2 \left(\frac{3S_R}{b_2} + 1\right) \exp\left(-\frac{3S_R}{2b_2}\right) \exp(i\pi k_2) + h_2 \left(\frac{3S_R}{b_3} + 1\right) \exp\left(-\frac{3S_R}{2b_3}\right) \exp(i\pi k_3)\right|^2.$$

It can easily be shown that for $k_2 = 1$ and $k_3 = 3$ there is a vacuum solution

$$S_R = O(1)\ \frac{9}{16\pi^2}$$

with zero vacuum energy density. The $N = 1$ supersymmetry can thus be broken by breaking the gauge group

$$E_8 \to SU(3) \otimes SU(2) .$$

In a supersymmetry breaking of this sort the gravitino mass is

$$m_{3/2} = \exp\left(\frac{\langle G \rangle}{2}\right) .$$

The presence of nonrenormalizable terms in the superpotential $W(C)$, which arise as a result of the interaction of massive excitation of the superstring with the observable fields C_X, also leads to breaking of the $N = 1$ supersymmetry. This method of breaking the supersymmetry can be used to obtain the standard low-energy gauge group $SU(3)^C \otimes SU(2)_L \otimes U(1)$ of the strong and electroweak interactions. The superpotential $W(C)$, which takes into account the interaction of massive excitations of the superstring with the observable (light) fields $27 = C$ and $\overline{27} = \overline{C}$, can be written

$$W = d_{XYZ} C_X C_Y C_Z + d_{XYZ} \overline{C}_X \overline{C}_Y \overline{C}_Z + \frac{\alpha}{2} (\overline{C}_X C_X)^2 + \frac{\beta}{3} (\overline{C}_X C_X)^3 + \dots . \qquad (5)$$

The equations for determining the effective-potential minimum

$$W'_C = 0, \quad W + \Delta W = 0 \qquad (6)$$

have a nontrivial vacuum solution

$$\langle C \rangle = \langle \overline{C} \rangle = \sqrt{-\alpha/\beta}. \qquad (7)$$

Solution (7) corresponds to the following gauge group breaking:

$$E_6 \to SO(10).$$

The gauge group SO(10) can be further broken due to the Hosotani mechanism.[8] The SO(10) gauge group in this case can be broken to the standard $SU(3)^C \otimes SU(2)_L \otimes U(1)$ gauge group. We note that if the Hosotani mechanism is used to break the E_6 gauge group, the low-energy gauge group will contain at least an additional U(1) gauge group, causing the predictions of the standard Weinberg-Salam model to be modified for the processes involving neutral currents.

I wish to thank J. Ellis, D. Niels, and V. A. Matveev for useful discussions.

[1]M. V. Green and J. Schwarz, Phys. Lett. **155B**, 365 (1984).
[2]D. Gross *et al.*, Nucl. Phys. **256B**, 253 (1985).
[3]P. Candelas *et al.*, Nucl. Phys. **258B**, 46 (1985).
[4]E. Witten, Phys. Lett. **155B**, 151 (1985).
[5]J. P. Dependinger, L. E. Ibanez, and H. P. Nilles, Nucl. Phys. **169B**, 354 (1986).
[6]M. Dine *et al.*, Phys. Lett. **156B**, 55 (1985).
[7]N. P. Nilles, Phys. Lett. **155B**, 193 (1982).
[8]Y. Hosotani, Phys. Lett. **126B**, 303 (1983).

Translated by S. J. Amoretty