Higgs bosons may be sneutrinos

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In a GUT scenario with unconventional supersymmetry, Higgs bosons can be sneutrinos.

The next few years are full of promise for historic discoveries in high-energy physics. One expects that both a Higgs boson [1-5] and supersymmetry [6-16] will be observed at either the Tevatron or the LHC [17-21], with more detailed exploration at a next-generation linear collider [22, 23].

It was proposed long ago that Higgs fields might be superpartners of lepton fields [24], but this original proposal was ruled out because of two problems: (1) With standard Yukawa couplings, lepton number would not be conserved. (2) This proposal is incompatible with standard supersymmetric models for more technical reasons [25].

Recently we proposed a very different scenario, in which both Yukawa couplings and supersymmetry have unconventional forms [26, 27]. The basic picture is an $SO(10)$ grand-unified gauge theory with the nonstandard supersymmetry described in Refs. 26 and 27.

(1) **Yukawa couplings.** Suppose that the first stage of symmetry-breaking at the GUT scale involves a Higgs field ϕ_{GUT} which is the superpartner of the charge-conjugate of a right-handed neutrino field ν_R. Then ϕ_{GUT} has a lepton number of -1 and an R-parity

$$R = (-1)^{3(B-L)+2s} = -1. \tag{1}$$

This picture is compatible with the minimal scheme [28]

$$SO(10) \to SU(5) \to SU(3) \times SU(2) \times U(1) \to SU(3) \times U(1). \tag{2}$$

More specifically, there are 16 scalar boson fields, in each of 3 generations, which are superpartners of the 16 fermion fields per generation in a standard $SO(10)$ theory. There are then 3 scalar bosons which are superpartners associated with right-handed neutrinos, and ϕ_{GUT} is a linear combination of these 3 bosonic fields.

Suppose also that symmetry-breaking at the electroweak scale involves a Higgs field ϕ_{EW} which is the superpartner of the charge-conjugate of a left-handed lepton field:

$$\phi_{EW} = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \quad , \quad \psi_\ell = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}. \tag{3}$$

In the simplest description, ν_L is the electron neutrino and e_L is the left-handed field of the electron.

Finally, suppose that a typical fermion field below the GUT scale has an effective Yukawa coupling with the form

$$\lambda_{eff} = \lambda_0 \frac{\left\langle \phi_{GUT}^\dagger \right\rangle}{m_{GUT}} \tag{4}$$

where λ_0 is dimensionless and $\left\langle \phi_{GUT}^\dagger \phi_{GUT} \right\rangle \sim m_{GUT}^2$ with $m_{GUT} \sim 10^{13}$ TeV. One then has a Dirac mass term

$$m\psi_L^\dagger \psi_R = \psi^\dagger \lambda_{eff} \left\langle \phi_{EW} \right\rangle \psi_R = \lambda_0 \psi^\dagger \frac{\left\langle \phi_{GUT}^\dagger \right\rangle}{m_{GUT}} \left\langle \phi_{EW} \right\rangle \psi_R \tag{5}$$

$$\psi = \begin{pmatrix} \psi_L' \\ \psi_L \end{pmatrix} \quad , \quad \left\langle \phi_{EW} \right\rangle = \begin{pmatrix} 0 \\ v/\sqrt{2} \end{pmatrix}. \tag{6}$$

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(There is another set of effective Yukawa couplings involving the charge-conjugate Higgs fields, of course.) Since both ϕ_{GUT} and ϕ_{EW} have a lepton number of -1, $\phi_{GUT}^{\dagger}\phi_{EW}$ conserves lepton number. The same is obviously true of the operator in $v^2/2 = \left\langle \phi_{EW}^{\dagger}\phi_{EW} \right\rangle$, which determines the masses of the W bosons [29].

Since the operator in (5) is effectively dimension-four below the grand-unification scale, the theory is renormalizable up to this scale. At energies above m_{GUT}, one has a dimension-five operator and the theory is no longer renormalizable, but this is exactly what one expects of a fundamental theory near the Planck scale [30].

(2) **Unconventional supersymmetry.** In the present context it is desirable to use the same broad definition of the term "supersymmetry" that was used in Ref. 26 (in accordance with previous usage in various contexts, including nonrelativistic problems [31-35]): A Lagrangian is supersymmetric if it is invariant under a transformation which converts fermions to bosons and bosons to fermions.

This is the fundamental meaning of supersymmetry: For every fermion there is a bosonic superpartner and vice-versa. It is this property that gives credibility to supersymmetry as a real feature of nature. For example, it permits the cancellation of fermionic and bosonic radiative contributions to the mass of the Standard Model Higgs, which would otherwise diverge quadratically. It also modifies the running of the $SU(3)$, $SU(2)$, and $U(1)$ coupling constants so that they can meet at a common energy m_{GUT}.

In addition to this primary physical motivation for supersymmetry, there is also a secondary and more mathematical aspect in the standard theories that are most widely discussed – namely, the algebra in which supersymmetric boson-fermion transformations of particle states are intimately connected to spacetime transformations of the inhomogeneous Lorentz group. However, there is no necessary logical connection between supersymmetry (as we have defined it above) and Lorentz invariance. Indeed, it is easily conceivable that some form of supersymmetry holds at the highest energies, up to the Planck scale, and that Lorentz invariance does not.

The supersymmetry of Refs. 26 and 27 has two unconventional aspects: First, Lorentz invariance is not postulated, but instead automatically emerges in the regimes where it has been tested – e.g., for gauge bosons and for fermions at energies that are far below the Planck scale. (The theory appears to be in agreement with the most sensitive experimental and observational tests of Lorentz invariance that are currently available, largely because many features of this symmetry are preserved, including rotational invariance, CPT invariance, and the same velocity c for all massless particles.) Second, gauge bosons are not fundamental, but are instead collective excitations of the GUT Higgs field. In the simplest picture, the first two stages of the symmetry-breaking depicted in (2) can be regarded as follows: (i) There are three scalar boson fields ϕ_{GUT}^{i} which are the superpartners of the charge-conjugates of three right-handed neutrino fields ν_R^i. (These three generations of right-handed neutrinos are a standard feature of $SO(10)$ grand unification [36-42]. Through the see-saw mechanism, they give rise to neutrino masses of about the right size to explain recent experimental observations [43-47].) In the first stage of symmetry-breaking, each of the initial GUT Higgs fields acquires a vacuum expectation value $\left\langle \phi_{GUT}^{i} \right\rangle$. At the same time, each ν_R^i acquires a large mass [28]. Then 3 complex bosonic fields and 3 fermionic fields are effectively lost. In the next stage depicted in (2), 24 real bosonic fields participate in the symmetry-breaking and are lost [28, 29]. Below m_{GUT}, however, one gains the initially massless vector bosons of the Standard Model, with $(8 + 3 + 1) \times 2 = 24$ bosonic degrees of freedom. The net result is that an equal number of bosonic and fermionic degrees of freedom are lost, and there is still supersymmetry below m_{GUT} down to some energy $m_{susy} \sim 1$ TeV where both bosons and fermions acquire unequal masses.

The particular version of supersymmetry in Refs. 26 and 27 permits a pairing of bosonic and fermionic fields like that in (3) because the initial superpartners consist only of spin zero bosons and spin 1/2 fermions, and because there is a relaxation of the restrictions imposed by Lorentz invariance. We conclude that there is at least one viable scenario in which Higgs bosons are sneutrinos, with an R-parity of -1.

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