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Exercise 8
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SS 06

Exercises on Elementary Particle Physics II

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1. *D-term SUSY breaking - part II*

   In this exercise we continue to discuss the details of D-term SUSY breaking (see Ex.7.2.). The U(1) gauge superfield is denoted by $V = (V_\mu, \lambda, D)$ and the left-chiral superfield by $\phi = (\varphi, \psi, F)$, having charge q.

   (a) Case $q\xi < 0$.

   From the shape of the scalar potential $V(\varphi)$, we see that the radial component of φ gets massive, while the angular component stays massless. Verify this by computation.

   Since φ is charged, the vev of $\varphi\varphi^*$ breaks the U(1) gauge symmetry. Compute the mass of the gauge boson V_μ.

   Is it possible to define a massive Dirac fermion? What is the relation between the Dirac mass and the mass of the gauge boson? Describe the SUSY-Higgs mechanism.

   Hint: The mass of the gauge boson arises from the term $(D_\mu\varphi(x))\,(D^\mu\varphi(x))^*$. The massive Dirac fermion is composed of ψ and the gaugino λ.

   (b) Case $q\xi > 0$.

   Show that all particles except for φ stay massless. Compute the mass of φ.

2. *The Minimal Supersymmetric Standard Model - part I*

   All standard model matter fields can be included in the following left-chiral superfields:

$$
\begin{array}{llll}
\text{quarks} & \mathbb{U}_i = \left(\mathbf{3}, \mathbf{2}, \tfrac{1}{6}\right) & \bar{U}_i = \left(\bar{\mathbf{3}}, \mathbf{1}, -\tfrac{2}{3}\right) & \bar{D}_i = \left(\bar{\mathbf{3}}, \mathbf{1}, \tfrac{1}{3}\right) \\
\text{leptons} & \mathbb{L}_i = \left(\mathbf{1}, \mathbf{2}, -\tfrac{1}{2}\right) & \bar{E}_i = (\mathbf{1}, \mathbf{1}, 1) & \\
\text{higgs} & H = \left(\mathbf{1}, \mathbf{2}, -\tfrac{1}{2}\right) & \bar{H} = \left(\mathbf{1}, \mathbf{2}, \tfrac{1}{2}\right) &
\end{array}
$$

   The index $i = 1, 2, 3$ labels the three generations of quarks and leptons.

   (a) How do the component fields (of e.g. $\mathbb{L}_i$) transform under gauge transformations? Why is the term $\mathbb{L}H\bar{E}$ gauge invariant?

(b) Write the most general, gauge invariant cubic superpotential for these superfields.

(c) Why do we need a second Higgs $\bar{H}$ in the MSSM?

(d) Identify the terms that conserve baryon and lepton number and those that do not. Verify that R-parity $R_p = (-1)^{3B+L+2s}$ forbids exactly those terms that violate baryon or lepton number.