Physikalisches Institut
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Theoretische Physik

Exercises 6
31 May 2010
SS 2010

Exercises on Theoretical Particle Physics II

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Due 06/07/2010

On the fourth exercise sheet, we discussed a simple SUSY model with a $U(1)$ gauge symmetry. The last exercise sheet was devoted SUSY breaking in general and to F-term breaking in particular. Now we want to discuss another SUSY breaking mechanism, namely D-term breaking. In case the theory has a $U(1)$ gauge symmetry, this can be done using the Fayet-Iliopoulos mechanism.

6.1 D-term SUSY Breaking (*17 credits*)

We consider the Lagrangian

$$\mathcal{L} = \int d^2\theta d^2\bar{\theta}[\Phi^\dagger e^{2qV}\Phi + 2\xi V] + \frac{1}{4}\int d^2\theta W^\alpha W_\alpha + \text{h.c.} \tag{1}$$

where $\Phi = (\varphi, \psi, F)$ is a chiral superfield, V a vector superfield (use WZ gauge), q the $U(1)$ charge of Φ, and ξ a real parameter (the Fayet-Iliopoulos parameter).

(a) On exercise sheet 4, it was shown that the last two terms in (1) are both SUSY and gauge invariant. Argue that the first term $[\Phi^\dagger e^{2qV}\Phi + 2\xi V]$ is invariant as well. (*2 credits*)

(b) Calculate $\mathcal{L}$ and the D-term equation of motion from (1). What is the scalar potential $V(\varphi)$? *Hint: Expand* $e^{2qV} = 1 + 2qV + 2q^2V^2 + \ldots$. *Work in WZ gauge and use the results from the previous exercise sheets.* (*6 credits*)

Now we want to discuss the two possible cases (i) $q\xi < 0$ and (ii) $q\xi > 0$.

(c) Which symmetries are broken in the cases (i) and (ii)? (*2 credits*)

(d) In **case (i)**, we see from the shape of the scalar potential $V(\varphi)$ that its radial component gets massive while its angular component stays massless. Verify this via a computation.
Since φ carries a charge, the vev $\langle\varphi^*\varphi\rangle$ breaks the $U(1)$ gauge symmetry. Calculate the resulting mass for the gauge boson V_μ. Is it possible to write down a massive Dirac fermion? What is the relation between the masses of the fermion and the gauge boson? Explain the SUSY Higgs mechanism. (*5 credits*)

(e) In **case (ii)**, all particles except φ stay massless. Show this via explicit calculation. Also calculate the mass of φ. (*2 credits*)