Physikalisches Institut
Universität Bonn
Theoretische Physik

Exercises 8
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SS 2014

Exercises on Theoretical Particle Physics II

Prof. Dr. H.P. Nilles

Due 2.6.2014

15. Flavor changing neutral currents (FCNCs) in the MSSM (*20 credits*)

(a) You already learned in part (b) of exercise 12 how to deduce terms from the Kähler potential. Take the Kähler potential terms for SQED

$$\mathcal{K} \supset \Phi_+^\dagger e^{2gV}\Phi_+ + \Phi_-^\dagger e^{-2gV}\Phi_-$$

with a vector superfield V and the two chiral superfields

$$\Phi_\pm = \phi_\pm + \sqrt{2}\theta\xi_\pm + \theta\theta F_\pm$$

where we used a slightly different notation than in previous exercises. Show that among others the component terms

$$\mathcal{L}_I = -\sqrt{2}g(\bar{\lambda}\bar{\xi}_+\phi_+ + \phi_+^\dagger\lambda\xi_+ - \bar{\lambda}\bar{\xi}_-\phi_- - \phi_-^\dagger\lambda\xi_-)$$

arise from the Kähler potential.

(*2 credits*)

(b) A physical fermion like the electron is a Dirac spinor and not a Weyl spinor. Use

$$\psi = \begin{pmatrix}\xi_+\\ \bar{\xi}_-\end{pmatrix}, \qquad \bar{\psi} = \begin{pmatrix}\xi_- & \bar{\xi}_+\end{pmatrix}, \qquad \lambda_M = \begin{pmatrix}\lambda\\ \bar{\lambda}\end{pmatrix}, \qquad \bar{\lambda}_M = \begin{pmatrix}\lambda & \bar{\lambda}\end{pmatrix}$$

together with $P_{L,R} = \frac{1}{2}(1 \mp \gamma_5)$ to rewrite the result from part (a) to

$$\mathcal{L}_I = -\sqrt{2}g(\bar{\psi}P_R\lambda_M\phi_+ + \phi_+^\dagger\bar{\lambda}_M P_L\psi - \phi_-\bar{\lambda}_M P_R\psi - \bar{\psi}P_L\lambda_M\phi_-^\dagger).$$

(*2 credits*)

(c) The result from part (b) can be promoted to SQCD with SU(3) gauge group

$$\mathcal{L}_I = -\sqrt{2}g_3(\bar{\psi}P_R T^a\lambda_M^a\phi_+ + \phi_+^\dagger\bar{\lambda}_M^a T^a P_L\psi - \phi_-\bar{\lambda}_M^a T^a P_R\psi - \bar{\psi}P_L T^a\lambda_M^a\phi_-^\dagger)$$

by introducing the generators T^a and changing the coupling constant. Show that this can also be written as

$$\mathcal{L}_I = -\sqrt{2}g_3(\bar{\psi}P_R T^a\lambda_M^a\phi_+ - \phi_-\bar{\lambda}_M^a T^a P_R\psi) + \text{h.c.}$$

(*2 credits*)

(d) Assume ψ is a quark and $\bar{\psi}$ the corresponding antiquark. Which fields in the notation from part (a) are the corresponding squarks $\tilde{q}_L$, $\tilde{q}_R$ and the corresponding antiquarks $\bar{\tilde{q}}_R$, $\bar{\tilde{q}}_L$?

(2 credits)

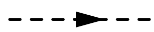
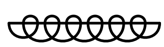
(e) Explain why the interaction terms of SQCD in part (c) give rise to

$$\mathcal{L}_I = -\sqrt{2} g_3 \left(\bar{d}_i P_R T^a \tilde{g}^a \left((U^{d_L})^\dagger U^{\tilde{d}_L} \right)_{ij} \tilde{d}_{jL} - \bar{\tilde{d}}_{iR} \left((U^{\tilde{d}_R})^\dagger U^{d_R} \right)_{ij} \bar{\tilde{g}}^a T^a P_R d_j \right) + \text{h.c.}$$

in the down quark sector of the MSSM. Which particles are described by $\tilde{g}^a$? Why do no SU(2) doublets appear here? Explain why the matrices U^{d_L} and $U^{\tilde{d}_L}$ appear. Why are these matrices unitary?

(2 credits)

(f) Look in your favourite text book or at pdg.lbl.gov how the Kaon K^0 and the corresponding antiparticle $\bar{K}^0$ are defined. Draw all possible Feynman diagrams up to one loop order involving supersymmetric particles for the process $K^0 \to \bar{K}^0$. This process is usually called $K^0 - \bar{K}^0$ mixing which is flavor changing. How does strangeness change in this process? All Feynman graphs will involve the interaction terms given in part (e). Use the convention

quark =  squark =  gluino = 

for the Feynman diagrams.

(4 credits)

(g) The calculation of the Feynman diagrams from part (f) is possible but tedious. We will here just focus on one possible contribution, namely $\bar{s}_L d_L \to \bar{d}_L s_L$. We can assume that the down quark mass matrix is diagonal. Use your result from part (f) and explain why the contribution is proportional to

$$I = \sum_{i,j} U^{\tilde{d}_L}_{di} (U^{\tilde{d}_L})^\dagger_{is} U^{\tilde{d}_L}_{dj} (U^{\tilde{d}_L})^\dagger_{js} \int \frac{d^4p}{(2\pi)^2} \frac{1}{(p^2 - m^2_{\tilde{g}})(p^2 - m^2_{\tilde{g}})(p^2 - m^2_{\tilde{d}_i})(p^2 - m^2_{\tilde{d}_j})}$$

where p is the internal momentum. What happens when the squark masses are universal $m_{\tilde{d}_i} = \tilde{m},\ \forall i$?

(2 credits)

(h) Use $m^2_{\tilde{d}_i} = \tilde{m}^2 + \Delta\tilde{m}^2_i$ and Taylor expand the integral in I about $\tilde{m}^2$. What is now the leading contribution to $K^0 - \bar{K}^0$ mixing from I? Because FCNC processes like $K^0 - \bar{K}^0$ mixing are measured with high precision they are a good test for standard model extensions. $K^0 - \bar{K}^0$ mixing is already very well described by standard model processes. Explain how the estimated SUSY contribution can be small. Which parameters have to be tuned to get such a result?

(4 credits)