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Two-loop low-energy effective action in Abelian supersymmetric Chern–Simons matter models

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Abstract

We compute two-loop low-energy effective actions in Abelian Chern–Simons matter models with $\mathcal{N}=2$ and $\mathcal{N}=3$ supersymmetry up to four-derivative order. Calculations are performed with a slowly-varying gauge superfield background. Though the gauge superfield propagator depends on the gauge fixing parameter, it is shown that the obtained results are independent of this parameter. In the massless case the considered models are superconformal. We demonstrate that the superconformal symmetry strongly restricts the form of two-loop quantum corrections to the effective actions such that the obtained terms have simpler structure than the analogous ones in the effective action of three-dimensional supersymmetric electrodynamics (SQED) with vanishing topological mass.

Keywords: Effective action; Extended supersymmetry; Chern–Simons model; Quantum electrodynamics

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1. Introduction

Three-dimensional gauge field theories have one important difference from the four-dimensional ones: they allow for a gauge invariant topological mass term described by the Chern–Simons action. In supersymmetric gauge theories, the Chern–Simons term appears to be crucial in construction of $\mathcal{N}=8$ and $\mathcal{N}=6$ superconformal models, known as the BLG [1–6] and ABJM [7] ones, which are central objects in the AdS_4/CFT_3 correspondence. As is stressed in the recent paper by John Schwarz [8], it is important to study the low-energy effective action in these models to check the conjecture that it describes the dynamics of probe M2 brane in the AdS_4 background.

Leaving the issue of low-energy effective action in ABJM and BLG models for further studies, in the present paper we consider a simple problem: what is the dependence of low-energy effective action in three-dimensional supersymmetric models on the topological mass $\mathfrak{m}=\frac{kg^2}{2\pi}$, where g is the three-dimensional gauge coupling constant and k is the Chern–Simons level. There are two special cases, $g\to\infty$ with k finite and $k=0$ with g finite. The latter corresponds to the gauge theory without the Chern–Simons term (e.g., SQED or SQCD) while the former case describes a gauge theory with infinitely large topological mass. The aim of this paper is to compare the structure of low-energy effective actions in three-dimensional gauge theories in these two particular cases.

We address this question by considering low-energy effective action in Abelian $\mathcal{N}=2$ supersymmetric gauge theories with matter. In the recent paper [9] the two-loop low-energy effective action in $\mathcal{N}=2$, $d=3$ SQED (with vanishing topological mass) was computed, owing to the background field method in $\mathcal{N}=2$, $d=3$ superspace [10–12]. In the present paper we consider a similar model, but with the Chern–Simons kinetic term for the gauge superfield rather than the Maxwell one (i.e., infinitely large topological mass). We compute two-loop low-energy effective action in this model up to the four-derivative order and compare it with the similar terms in the effective action of $\mathcal{N}=2$, $d=3$ SQED with vanishing topological mass considered in [9]. To be more precise, we consider a part of the effective action which includes only the gauge superfield because these terms can be naturally compared with the ones studied in [9]. In general, the effective action involves also contributions with the chiral matter superfields which are not considered here. The study of such terms in the effective action is a separate problem.

The one-loop effective action in gauge superfield sector (supersymmetric one-loop Euler–Heisenberg effective action) originates from the loop of matter chiral superfields with external gauge superfield. It is independent of both couplings g and k. So, we have to consider the two-loop effective action to study the problem described above. In three-dimensions, the $\mathcal{N}=2$ gauge superfield V has not only Grassmann-odd superfield strengths W_α and $\bar{W}_\alpha$, but also the Grassmann-even scalar superfield strength G. Up to four-derivative order, the low-energy effective action for these superfields has the following structure (see Section 2.2 for a more detailed discussion):

$$\Gamma=\int d^7z\big[f_1(G)+f_2(G)W^\alpha\bar{W}^\beta N_{\alpha\beta}+f_3(G)W^2\bar{W}^2\big], \tag{1.1}$$

where $f_i(G)$ are some functions and $N_{\alpha\beta}=D_\alpha W_\beta$. In the present paper we find two-loop quantum contributions to the functions $f_i(G)$ and compare them with similar results in the $\mathcal{N}=2$, $d=3$ SQED without the Chern–Simons term.

The function $f_1(G)$ in (1.1) is the leading term in the low-energy effective action for the gauge superfield. In components, it is responsible for the F^2 terms and its supersymmetric completions,