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TWO-LOOP EFFECTIVE ACTION IN $\mathcal{N}=2$, $D=3$ SUPERSYMMETRIC ABELIAN CHERN-SIMONS-MATTER MODEL WITH ONE CHIRAL SUPERFIELD

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Using a slowly-varying gauge superfield background we compute two-loop low-energy effective action in three dimensional $\mathcal{N}=2$ supersymmetric Abelian Chern-Simons-matter model with one chiral superfield up to four-derivative order.

Keywords: *effective action, extended supersymmetry, Chern-Simons field models.*

1 Introduction

The modern interest to three-dimensional supersymmetric field models is partly motivated by progress in constructing field theories describing multiple M2 branes in the $\mathrm{AdS}_4/\mathrm{CFT}_3$ correspondence. These are $\mathcal{N}=8$ and $\mathcal{N}=6$ three-dimensional superconformal models of Chern-Simons gauge fields interacting with matter, known as the BLG [1–3] and ABJM [4] ones. As was mentioned by John Schwarz [5], 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.

Following this general motivation we study the low-energy effective action in the simplest three-dimensional Abelian $\mathcal{N}=2$ supersymmetric Chern-Simons-matter theory with one chiral superfield. Thanks to the background field method in $\mathcal{N}=2$, $d=3$ superspace [6–10] we compute two-loop low-energy effective action in this model up to the four-derivative order. Because of the superconformal symmetry two-loop contributions to the effective action is strongly restricted. The one-loop effective action in gauge superfield sector (supersymmetric one-loop Euler-Heisenberg effective action) was obtained in [8].

We base our consideration on the work [11].

2 General structure of effective action

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.

The action of three-dimensional $\mathcal{N}=2$ supersymmetric Abelian Chern-Simons matter model with one chiral superfield has the form

$$S[V,Q]=\frac{k}{2\pi}\int d^7z\,VG-\int d^7z\,\bar{Q}e^{2V}Q\,. \tag{1}$$

The main goal for us is to study the low-energy effective action in the model under consideration (1) in the gauge superfield sector. In general, it is given by a functional of superfield strengths G, W_α, $\bar{W}_\alpha$ and their derivatives, $N_{\alpha\beta}=D_\alpha W_\beta$, $\bar{N}_{\alpha\beta}=\bar{D}_\alpha\bar{W}_\beta$,

$$\Gamma=\int d^7z\,\mathcal{L}(G,W_\alpha,\bar{W}_\alpha,N_{\alpha\beta},\bar{N}_{\alpha\beta},\ldots)\,, \tag{2}$$

where dots denote higher-order derivatives of the superfield strengths. It is hard problem to find the effective action (2) taking into account all derivatives of the fields. Thus, we restrict our consideration on the terms with no more than four space-time derivatives of component fields. For this aim it is enough to consider the following constraint on the superfield strengths:

(i) Supersymmetric Maxwell equations,

$$D^\alpha W_\alpha=0\,,\qquad \bar{D}^\alpha\bar{W}_\alpha=0\,; \tag{3}$$

(ii) Superfield strengths are constant with respect to the space-time coordinates,

$$\partial_m G=\partial_m W_\alpha=\partial_m\bar{W}_\alpha=0\,. \tag{4}$$

The equations (3) and (4) single out the slowly varying gauge superfield background. Also we note that the superfields $N_{\alpha\beta}$ and $\bar{N}_{\alpha\beta}$ and not independent under the constraints (3) and (4),

$$N_{\alpha\beta}=-\bar{N}_{\alpha\beta}\,. \tag{5}$$

Therefore, in what follows we keep only $N_{\alpha\beta}$ and discard $\bar{N}_{\alpha\beta}$.

Under the constraints (3) and (4) the effective action (2) which contains the terms with no more than four derivatives is given by

$$\Gamma = \int d^7z \left[f_1(G) + f_2(G)W^\alpha \bar{W}^\beta N_{\alpha\beta} + f_3(G)W^2\bar{W}^2\right], \quad (6)$$

with some functions $f_i(G)$, $i = 1, 2, 3$.

3 Two-loop contributions to effective action

The one-loop contributions to the functions $f_i(G)$ (6) for the model (1) were found in [8],

$$f_1^{(1)} = \frac{1}{4\pi} G \ln G\,, \quad f_2^{(1)} = 0\,, \quad f_3^{(1)} = \frac{1}{256\pi}\frac{1}{G^5}\,. \quad (7)$$

Our aim now is to compute two-loop corrections to this result, i.e., to find $f_i^{(2)}$.

The two-loop contribution to the effective action has the form

$$\Gamma^{(2)} = -\frac{15}{512\pi k_{\rm eff}} \int d^7z \frac{W^2\bar{W}^2}{G^5}\,. \quad (8)$$

Here $k_{\rm eff}$ is the effective Chern-Simons level which includes one-loop correction to the classical value.

The effective action (8) corresponds to the following values of the functions $f_i^{(2)}$ in (6),

$$f_1^{(2)} = f_2^{(2)} = 0\,, \qquad f_3^{(2)} = -\frac{15}{512\pi k_{\rm eff}}\frac{1}{G^5}\,. \quad (9)$$

Since the model (1) is superconformal [8], the two-loop effective action (8) can be represented in a superconformal form by adding the terms with $D^\alpha W_\alpha$ and $\bar{D}^\alpha \bar{W}_\alpha$. The action (8) can be rewrite as follows

$$\Gamma^{(2)} = \frac{15}{256\pi k_{\rm eff}} \int d^7z \frac{(D^\alpha \bar{D}_\alpha \ln G)^2}{G}\,. \quad (10)$$

After summarizing one- and two-loop contributions, we get the parity-even part of the two-loop effective action in the superconformal form,

$$\Gamma_{\rm even} = \Gamma^{(1)} + \Gamma^{(2)} = \frac{1}{4\pi}\int d^7z\, G\ln G + \frac{1}{128\pi}\left(\frac{15}{2k_{\rm eff}} - 1\right)\int d^7z \frac{(D^\alpha \bar{D}_\alpha \ln G)^2}{G}\,. \quad (11)$$

The effective action (11) is represented in the superconformal form and represents the parity-even part of the low-energy effective action in the model (1) up to the four-derivative order.

4 Conclusion

In the present paper we considered the model (1) in which the gauge superfield is described by the Chern-Simons action. In these models we computed two-loop low-energy effective action (11) up to four-derivative order in the gauge superfield sector. We demonstrate, that superconformal invariance restrict the possible contributions to the effective action. It should be noted that any superconformal effective action for the $\mathcal{N} = 2$ gauge superfield can be expressed in terms of superconformal invariants classified in [8].

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ДВУХПЕТЛЕВОЕ НИЗКОЭНЕРГЕТИЧЕСКОЕ ЭФФЕКТИВНОЕ ДЕЙСТВИЕ В $\mathcal{N} = 2$, $d = 3$ СУПЕРСИММЕТРИЧНОЙ АБЕЛЕВОЙ МОДЕЛИ ПОЛЯ ЧЕРНА-САЙМОНСА С МАТЕРИЕЙ

Для случая медленно меняющегося фонового калибровочного суперполя вычислено двухпетлевое низкоэнергетическое эффективное действие в трехмерной $\mathcal{N} = 2$ суперсимметричной абелевой модели поля Черна-Саймонса, взаимодействующего с одним киральным суперполем, с точностью до производных четвертого порядка от компонентных полей.

Ключевые слова: *эффективное действие, расширенная суперсимметрия, модели с полями Черна-Саймонса.*

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