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Anomaly cancellation in effective supergravity theories from the heterotic string: Two simple examples ☆

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Abstract

We use Pauli–Villars regularization to evaluate the conformal and chiral anomalies in the effective field theories from Z_3 and Z_7 compactifications of the heterotic string without Wilson lines. We show that parameters for Pauli–Villars chiral multiplets can be chosen in such a way that the anomaly is universal in the sense that its coefficient depends only on a single holomorphic function of the three diagonal moduli. It is therefore possible to cancel the anomaly by a generalization of the four-dimensional Green–Schwarz mechanism. In particular we are able to reproduce the results of a string calculation of the four-dimensional chiral anomaly for these two models.

1. Introduction

On-shell Pauli–Villars regularization of the one-loop divergences of supergravity theories was used to determine the anomaly structure of supergravity in [1]. Pauli–Villars regulator fields

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allow for the cancellation of all quadratic and logarithmic divergences [2], as well as most linear divergences [1]. If all linear divergences were canceled, the theory would be anomaly free, with noninvariance of the action arising only from Pauli–Villars masses. However there are linear divergences associated with nonrenormalizable gravitino/gaugino interactions that cannot be canceled by PV fields. The resulting chiral anomaly forms a supermultiplet with the corresponding conformal anomaly, provided the ultraviolet cut-off has the appropriate field dependence, in which case uncanceled total derivative terms, such as Gauss–Bonnet, do not drop out from the effective action. The resulting anomaly term that is quadratic in the field strength associated with the space–time curvature, as well as the term quadratic in the Yang–Mills field strength, was shown in [1] to be canceled by the four-dimensional version of the Green–Schwarz mechanism in Z_3 and Z_7 compactifications, in agreement with earlier results [3]. However, the terms in the anomaly that are quadratic and cubic in the parameters of the anomalous transformation are prescription dependent [4,1]. The choice of PV fields with noninvariant masses used in [1] did not achieve full anomaly cancellation.

Every contribution to the chiral anomaly has a conformal anomaly counterpart, with which it combines to form an "F-term" anomaly. In addition there are "D-term" anomalies associated with logarithmic divergences that have no chiral partner. In a generic supergravity theory, these include terms [1] that are nonlinear in the holomorphic functions $F^i(T^i)$ of the three diagonal Kähler moduli T^i that characterize modular (or T-duality) transformations:

$$\begin{aligned} T'^i &= \frac{a_i - i b_i T^i}{i c_i T^i + d_i}, \qquad a_i b_i - c_i d_i = 1, \qquad a_i, b_i, c_i, d_i \in \mathbf{Z}, \\ \Phi'^a &= e^{-\sum_i q_i^a F^i(T^i)} \Phi^a, \qquad F^i(T^i) = \ln(i c_i T^i + d_i), \end{aligned} \tag{1.1}$$

where Φ^a is any chiral supermultiplet other than a diagonal Kähler modulus, and q_i^a are its modular weights. Only terms in the anomaly that are linear in $F = \sum_i F^i$ can be canceled by the Green–Schwarz term.

In addition, in generic supergravity there are anomalous terms that involve the dilaton superfield S in the chiral supermultiplet formulation or L in the linear multiplet formulation [5] for the dilaton. Specifically, one expects [6] a term quadratic in the Kähler field strength

$$X_{\mu\nu} = \left(\mathcal{D}_\mu z^i \mathcal{D}_\nu \bar{z}^{\bar{m}} - \mathcal{D}_\nu z^i \mathcal{D}_\mu \bar{z}^{\bar{m}} \right) K_{i\bar{m}} - i F^a_{\mu\nu} (T_a z^i) K_i, \tag{1.2}$$

where $z^i = Z^i \big|$ is the scalar component of a generic chiral superfield Z^i, $F^a_{\mu\nu}$ is the gauge field strength, T_a is a gauge group generator, and $K(Z, \bar{Z})$ is the Kähler potential. The term quadratic in $X_{\mu\nu}$ was actually found to vanish in [1], but there remained terms linear in $X_{\mu\nu}$ as well as terms involving the Kähler potential in the nonlinear F^i terms mentioned above. Anomaly cancellation by a Green–Schwarz mechanism, to be outlined in the next section, requires that the operators appearing in the anomaly also appear in the real superfield Ω of the (modified) linearity condition for the superfield L:

$$\begin{aligned} &\left(\bar{\mathcal{D}}^2 - 8R \right) (L + \Omega) = \left(\mathcal{D}^2 - 8\bar{R} \right) (L + \Omega) = 0, \qquad \mathcal{D}^2 = \mathcal{D}^\alpha \mathcal{D}_\alpha, \\ &\bar{\mathcal{D}}^2 = \mathcal{D}_{\dot{\alpha}} \mathcal{D}^{\dot{\alpha}} = (\mathcal{D}^2)^\dagger, \end{aligned} \tag{1.3}$$

where $\mathcal{D}_\alpha$ is a spinorial derivative and $R = \bar{R}^\dagger$ is the auxiliary field of the supergravity multiplet whose vev determines the gravitino mass: $\langle R | \rangle = \frac{1}{2} m_{\frac{3}{2}}$. The action written in terms of L is related to the action written in terms of S by a superfield duality transformation; the standard derivation of the duality transformation requires that Ω be independent of S. It was shown in