Possible resolution of the Λ-term problem in an $N = 1$ supergravity

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A class of superpotentials for which the cosmological Λ term automatically vanishes at the minimum is proposed for an $N = 1$ supergravity. In this approach the vacuum is degenerate with respect to both the symmetric and asymmetric phases. This circumstance may have some nontrivial consequences for cosmology.

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There can be no doubt that the Λ-term problem[1] is one of the most serious and interesting problems in the theory of elementary particles and cosmology (see the review by Langacker).[2] According to observational data, the vacuum energy density is

$$\frac{\Lambda M_{PL}^2}{8\pi} = |\epsilon_{\mathrm{vac}}| < (2\times 10^{-9}\ \mathrm{MeV})^4,$$

or far smaller than all the characteristic energies of the physics of elementary particles.[2] A zero vacuum energy occurs naturally in theories with unbroken supersymmetry and supergravity.[3] In the real world, however, supersymmetry (both global and local) must be broken, so that the Λ-term problem remains equally important for the "super" theories.

In this letter we wish to call attention to the circumstance that in an $N=1$ supergravity it is possible to resolve the Λ-term problem for a certain special class of superpotentials, at least at the tree level, by analogy with the way in which supersymmetry resolves the hierarchy problem.[1)] In this approach, the Λ-term vanishes for both symmetric and asymmetric vacuums.

Weinberg[4] has shown for a specific model that supergravity effects cause a splitting of the supersymmetry vacuums. In the models that we are proposing here, on the other hand, the degeneracy of the vacuums remains even when supergravity effects are taken into account.

The effective potential in an $N=1$ supergravity is[5,7]

$$U = \exp\left(\sum_{i=1}^{N} \frac{|\varphi_i|^2}{M^2}\right)\left\{\left|\frac{\partial V}{\partial\varphi_i} + \varphi_i^* \frac{V}{M^2}\right|^2 - \frac{3|V|^2}{M^2}\right\} + \frac{1}{2}|D_\alpha|^2 , \tag{1}$$

where $V(\varphi_i)$ is the superpotential $D_a = g\varphi^+ T_\alpha \varphi$, T_α are the generators of the gauge group, and $M = M_{PL}/\sqrt{8\pi}$. For an $N=1$ supergravity the parameter of the breaking of the global supersymmetry is $|\partial V/\partial\varphi_i|\, |\varphi_i = \varphi_i^{\min}$, and the parameter of the breaking of the local supersymmetry is[3] $|V(\varphi_i)|\varphi_i = \varphi_i^{\min}$. From (1) we see that it is possible in principle to break the global and local supersymmetries in such a manner that we have $U=0$ at the minimum. For this purpose we must have the following at the minimum:

$$\left|\left(\frac{\partial V}{\partial\varphi_i} + \varphi_i^* \frac{V}{M^2}\right)\right|^2 - \frac{3|V|^2}{M^2} = 0.$$
$$D_\alpha = 0. \tag{2}$$

In the case of an arbitrary superpotential, however, which depends on many scalar fields φ_i in realistic models, condition (2) generally breaks down at the minimum. Can we restrict the class of allowed superpotentials in such a manner that condition (2) holds automatically at the minimum, as the *CP* invariance of the vacuum at the minimum follows automatically from the Peccei-Quinn chiral symmetry?

As a simple ansatz we introduce the canceling superpotential $V_K(z)$, which depends on the gauge-invariant complex field z in such a manner that for all z the following holds:

$$\left|\frac{\partial V_K}{\partial z} + z^* \frac{V_K}{M^2}\right|^2 - \frac{3|V_K|^2}{M^2} \geqslant 0. \tag{3}$$

Some simple examples of a canceling superpotential are

$$V_K(z) = \frac{z}{M} + 2 - \sqrt{3}, \tag{4}$$

$$V_K(z) = \left(\frac{z}{M}\right)^{3/4} . \tag{5}$$

We will use canceling superpotential (4) below. We consider a superpotential in the factorized form

$$V(z, \varphi_i) = V_K(z) V(\varphi_i). \quad (6)$$

The effective potential (1) for superpotential (6) is

$$U = \exp\left(\sum_{i=1}^{N} \frac{|\varphi_i|^2}{M^2} + \frac{|z|^2}{M^2}\right)\left\{\left(\left|\frac{\partial V_K}{\partial z} + \frac{z^* V_K}{M^2}\right|^2 - 3\frac{|V_K|^2}{M^2}\right)|V(\varphi_i)|^2 + |V_K|^2\left|\frac{\partial V}{\partial \varphi_i} + \varphi_i^* \frac{V}{M^2}\right|^2\right\} + \frac{1}{2}|D_\alpha|^2. \quad (7)$$

It is not difficult to see that $U(z,\varphi_i) \geqslant 0$. The condition for the vanishing of the cosmological constant at the minimum is

$$\frac{\partial V}{\partial \varphi_i} + \frac{\varphi_i^* V}{M^2} = 0, \quad (8)$$

$$D_\alpha = 0.$$

Equation (8) has a nontrivial solution with $|V| \neq 0$ for a broad range of superpotentials. For the factorized superpotential (6), a zero energy density at the minimum is therefore achieved automatically if the canceling superpotential is chosen correctly. It is difficult at present to cite any convincing arguments for ansatz (6), which apparently provides the simplest solution of the Λ-term problem.

For realistic models of the SU(5) type, Eq. (8) has both an SU(5)-symmetry solution and a solution that breaks SU(5) to SU(3) ⊗ SU(2) ⊗ U(1), and this circumstance may have some nontrivial consequences for cosmology. Specifically, we know that at high temperatures the universe must be in a symmetric phase. As the temperature decreases, on the other hand, the temperature effects may carry the SU(5) phase into an SU(3) ⊗ SU(2) ⊗ U(1) phase according to the model of this paper, in contrast with Weinberg's model.[4] This question requires further study, however.

In conclusion we wish to emphasize again that the most characteristic feature of this new approach is the absence of a Λ term for both the symmetric and asymmetric phases.

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[1)]Attempts have been made[6] to solve the Λ-term problem by working from theories of the Kaluza-Klein type.

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