Broken Symmetry and the Cosmological Constant

Joseph Dreitlein
Department of Physics and Astrophysics, University of Colorado, Boulder, Colorado 80302
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The hypothesis that the Higgs field has also a cosmological character is proposed. The experimental consequences are an upper limit on the mass of the scalar boson, $m_\varphi < 4.6 \times 10^{-27} m_e$, and an implication that the universe will recontract.

Several recent developments[1,2] in particle physics portend the exciting possibility of attaining the long-sought relations among the various types of particle interactions. While weak, electromagnetic, and strong interactions can be amalgamated by a variety of stratagems, the gravitational interaction still stands alone. It is the purpose of this Letter to propose the remote possibility that a relationship exists between spontaneously broken gauge theories and the cosmological constant. To date, the Higgs particle(s), *deus ex machina,* have eluded experimental detection. This could be a result of the predicted very small coupling constant even though the mass is assumed arbitrary.[3] The following proposition ascribes a cosmological significance to these particles.

All gauge theories with spontaneously broken symmetry start with a manifestly symmetric Lagrangian. It seems reasonable to suppose that the original symmetric Lagrangian has a *physical* meaning. I implement this concept of reality by requiring that the energy-momentum tensor $T_{\mu\nu}$ formed from the Lagrangian have zero expectation value for the symmetric vacuum. The physically realized vacuum or asymmetric vacuum then has a nonzero expectation value for $T_{\mu\nu}$. The origin of the nonvanishing of $\langle T_{\mu\nu}\rangle$ is the nonvanishing of the Higgs-field vacuum expectation value, an important ingredient in Weinberg-Salam–type renormalizable theories.

Einstein's gravitational field equations connect the energy-momentum tensor $T_{\mu\nu}$ to space-time structure via the Ricci tensor:

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = (8\pi G/c^4) T_{\mu\nu}. \tag{1}$$

Here G is the gravitation coupling constant and the signature of $g_{\mu\nu}$ is (+, −, −, −). The assumption that the vacuum expectation value of $T_{\mu\nu}$ is nonvanishing and physically meaningful leads to the equation

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = \Lambda g_{\mu\nu}, \tag{2}$$

with

$$\Lambda g_{\mu\nu} = (8\pi G/c^4)\langle T_{\mu\nu}\rangle. \tag{3}$$

The vacuum value of $T_{\mu\nu}$ thus appears in the form of a cosmological term in the vacuum field equations. Zel'dovitch and Novikov[4] have already conjectured such a meaning for the cosmological constant.

For the specific case of the Weinberg-Salam SU(2)⊗ U(1) gauge symmetry, specific consequences follow from the above proposal. The conclusions are to a great extent model independent. If $V(\varphi)$ is the "potential" term in the Higgs-field Lagrangian, then the only nonvanishing part of $\langle T_{\mu\nu}\rangle$ (constructed by the canonical procedures of field theory) is

$$\langle T_{\mu\nu}\rangle = g_{\mu\nu}\langle V(\varphi)\rangle,$$
$$V(\varphi) = \mu^2 \varphi^\dagger\varphi + \lambda(\varphi^\dagger\varphi)^2 \quad (\mu^2 < 0). \tag{4}$$

Let $v/\sqrt{2}$ be the (real) vacuum expectation value of φ, so that

$$V(\varphi) = \mu^2 v^2/4. \tag{5}$$

These parameters are related to physical parameters:

$$m_\varphi^2 = -2\mu^2,$$
$$v^2 = 4M_w^2/g^2 = 1/\sqrt{2}G_F. \tag{6}$$

Here m_φ and m_w are the masses of the Higgs scalar and the weak vector boson, respectively. The coupling constant g is related to the electromagnetic coupling constant e and the γ-Z mixing angle Θ by

$$e = g \sin\Theta. \tag{7}$$

The measured constant G_F is the Fermi weak-coupling constant. Putting together the above ingredients yields

$$\Lambda = -(\pi G/\sqrt{2}G_F) m_\varphi^2 \tag{8}$$

($\hbar = c = 1$). Now an upper limit[5] exists experimentally for the value of Λ and consequently implies an upper limit on m_φ:

$$m_\varphi < 4.6\times10^{-27} m_e. \quad (9)$$

So far as elementary-particle physics is concerned, the Higgs particle is massless, a property not inconsistent with experiment.[3] (It is interesting to note that if m_φ arises gravitationally, then $\lambda \sim G \sim \mu^2$ and the necessary factor of smallness arises here but in a more intricate fashion than previously surmised.[4])

There are a number of consequences which ensue. If it be granted that the electron mass originates from spontaneous symmetry breakdown via the Higgs mechanism, then φ is weakly coupled to the electron with coupling constant

$$G_\varphi \sim 2\times10^{-6}. \quad (10)$$

This small coupling inhibits easy production and makes it plausible that the particle has escaped detection. If the Higgs particle is effectively massless, however, it must also couple to the proton with a sign opposite to the electron coupling, otherwise matter would collapse under this weak but coherent long-ranged "scalar" electrodynamic force. One place to look for the particle is in the $0^+ \to 0^+$ transition in ^{16}O.

If the assumption is made that the universe at the present epoch is isotropic, a second consequence of the model, somewhat more speculative, ensues. The appearance of a term with the cosmological constant in the equations governing the evolution of the universe implies that the universe will eventually contract.[6] This follows from the property that the cosmological constant is negative [Eq. (8)] independent of the φ mass as long as it is nonzero. A nonzero value of m_φ is required for the Higgs mechanism to work in the usually assumed manner. It seems striking that the absence of both nonrenormalizable ultraviolet divergences in weak interactions and a divergent expansion of the universe might have something in common. If T nonconservation originates from spontaneous breakdown of symmetry as, for example, in the Lee model,[7] then the Higgs field could conceivably also put the nonconservation in a cosmological context.

The discovery of a nearly massless scalar field with a weak coupling is a necessary condition for the validity of the hypothesis that the Higgs field is also a cosmological field.

I hope to report more detailed consequences of the cosmological hypothesis in the near future.

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[2]For review articles containing the details, see E. S. Abers and B. W. Lee, Phys. Rep. 9C, 1 (1973); K. T. Mahanthappa, "Lectures on Spontaneously Broken Gauge Theories," 1973 (unpublished).

[3]R. Jackiw and S. Weinberg, Phys. Rev. D 5, 2396 (1972).

[4]Ya. B. Zel'dovitch and I. D. Novikov, *Relativistic Astrophysics* (Univ. of Chicago Press, Chicago, Ill., 1971), Vol. 1, pp. 28 ff.

[5]C. W. Misner, K. S. Thorne, and J. A. Wheeler, *Gravitation* (Freeman, San Francisco, 1973), p. 411.

[6]Misner, Thorne, and Wheeler, Ref. 5, p. 747.

[7]T. D. Lee, Phys. Rep. 9C, 143 (1974).

Scalar Models of Weak Interactions*

Gino Segrè
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19174
(Received 17 September 1974)

A model of weak interactions mediated by scalar bosons $B^\pm$, B^0, and $\bar{B}^0$ is presented.

The recent discovery[1-4] of muonless neutrino scattering events has lent strong credence to the essential correctness of some form of the Weinberg-Salam theory[5,6] of weak interactions. It seems particularly important to see now whether the data can be fitted by other theories as well; in this spirit I wish to discuss a class of renormalizable models of weak interactions. They are basically elaborations of models discussed years ago,[7-11] modified by a few new observations.

The characteristic feature is that the weak interactions are mediated by scalar bosons, $B^\pm$, B^0, and