PHYSICAL REVIEW D VOLUME 14, NUMBER 12 15 DECEMBER 1976

High-density and high-temperature symmetry behavior in gauge theories

A. D. Linde*
International Centre for Theoretical Physics, Trieste, Italy
(Received 12 May 1976)

It is shown that in most of the gauge theories with neutral currents an increase of fermion density leads to an *increase* of symmetry breaking. The symmetry behavior at a simultaneous increase of temperature and density is also investigated. It proves in particular that there was no symmetry restoration in the early universe if, at present, an excess of neutrinos over antineutrinos is sufficiently large.

I. INTRODUCTION

Symmetry behavior in gauge theories under an influence of such external factors as temperature,[1-6] density increase,[5,7-9] external fields,[5,10-12] and currents[8] has been extensively studied in the past few years. In particular, Kirzhnits has suggested[1] that in the theories with spontaneous symmetry breaking at a sufficiently high temperature a phase transition with the symmetry restoration should take place. This suggestion has been confirmed by a detailed investigation of the high-temperature symmetry behavior in gauge theories.[2-6] It appears that the phase transition with symmetry restoration may be of the first[5] or the second[2-5] order depending on relations between coupling constants, and a general theory of the phase transition, valid for all relations between coupling constants, has been presented.[5,6] It was shown in particular that at certain relations between coupling constants the first-order phase transition may take place even at an extremely low critical temperature T_c. For example, in the Higgs model $T_c \to 0$ at $\lambda \to 19e^4/32\pi^2$, since at $\lambda < 19e^4/32\pi^2$ a dynamical symmetry restoration takes place.[6]

The fact that the classical scalar field, which breaks symmetry in gauge theories, is temperature-dependent leads to some nontrivial consequences, e.g. to a temperature dependence of the cosmological term,[13] and (which seems the most interesting) to nonconservation of energy of an observable part of matter due to the "pumping" of energy from the nonobservable classical scalar field.[4,5]

Recently, in a number of papers it was claimed that an increase of fermion density at zero temperature also leads to symmetry restoration.[7] However, as was pointed out in Ref. 8, in most of the realistic gauge theories with neutral currents (either "weak" or "strong," corresponding to the interactions mediated by ρ, ω, and φ mesons) the result is actually opposite; an increase of the "weak" or "strong" charge density of fermions leads to an *increase* of symmetry breaking.

This result can easily be understood if one recalls that an increase of an external fermion current $\vec{\mathcal{J}}$ leads to the symmetry restoration in the superconductivity theory.[14] In gauge theories symmetry breaking must be a function of $\mathcal{J}^2 = \mathcal{J}_0^{\,2} - \vec{\mathcal{J}}^2$, where $\mathcal{J}_0^{\,2}$ is the charge density of fermions. Since, e.g., the Higgs model is in fact a covariant generalization of the Ginzburg-Landau theory of superconductivity, one may expect that an increase of $\vec{\mathcal{J}}^2$ should lead to symmetry restoration in guage theories, while an increase of fermion charge density $\mathcal{J}_0^{\,2}$ should lead to a further increase of the symmetry breaking. To make this suggestion clearer, we outline the quantitative analysis of this problem in Sec. II.[8]

The effects of the type discussed above may appear of particular interest for the theory of the early stages of the universe evolution. However, in the early universe both temperature and fermion charge density were extremely high. Therefore to investigate symmetry behavior in the early universe it is necessary to take into account the two opposed factors (temperature and density increase) simultaneously. This problem is discussed in Sec. III.

In Sec. IV some consequences of the high-temperature and high-density symmetry behavior for the theory of the early universe are discussed. It proves in particular that there was no symmetry restoration in the early universe if at present an excess of neutrinos over antineutrinos is sufficiently large.

II. HIGH-DENSITY SYMMETRY BEHAVIOR IN GAUGE THEORIES

As an example we shall consider the Higgs model, extended by the inclusion of fermions[8]:

$$L = -\tfrac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)^2 + (\partial_\mu + ieA_\mu)\varphi^*(\partial_\mu - ieA_\mu)\varphi + \mu^2\varphi^*\varphi - \lambda(\varphi^*\varphi)^2 + \bar{\psi}(i\partial_\mu\gamma_\mu - m)\psi - e\bar{\psi}\gamma_\mu\psi A_\mu \,. \tag{1}$$

Let us suppose that there exists a nonvanishing fermion current density $\mathcal{J}_\mu \equiv ej_\mu = e\langle\bar{\psi}\gamma_\mu\psi\rangle = \text{const} \neq 0$. Here $\langle\cdots\rangle$ is statistical averaging; the quantity j_μ differs from zero owing to a nonvanishing chemical potential of fermions.[7] The current being constant, there is no reason to expect breaking of translational invariance. Therefore in the unitary (physical) gauge we shall try to find a solution in the form

$$\varphi(x)=\frac{1}{\sqrt{2}}[\sigma+\rho(x)]\exp\left[\frac{i\xi(x)}{\sigma}\right],$$
$$A_\mu(x)=B_\mu(x)+C_\mu+\frac{1}{e\sigma}\partial_\mu\xi(x), \tag{2}$$

where the classical parts σ and C_μ of the fields ρ and B_μ are some constants, $\langle\rho(x)\rangle=\langle B_\mu(x)\rangle=0$, and the auxiliary field $\xi(x)$ disappears after substitution of (2) into (1).

The quantities σ and C_μ can be obtained from the Lagrange equations averaged over the ground state. In the lowest approximation these equations are

$$\left\langle\frac{\delta L}{\delta\rho(x)}\right\rangle=0=-\sigma(\lambda\sigma^2-\mu^2)+e^2C_\mu{}^2\sigma,$$
$$\left\langle\frac{\delta L}{\delta B_\mu}\right\rangle=0=e^2C_\mu\sigma^2-ej_\mu. \tag{3}$$

These equations are nothing but a covariant generalization of the Ginzburg-Landau equations in the theory of superconductivity.[14] From (3) it follows that

$$\sigma(\lambda\sigma^2-\mu^2)-\frac{j^2}{\sigma^3}=0, \tag{4}$$

where $j^2=j_0{}^2-\vec{j}^2$. From Eq. (4) it can easily be seen that (as in the theory of superconductivity) an increase of the current $\vec{j}$ leads to the symmetry restoration in the Higgs model,[8] whereas an increase of the fermion charge density j_0 increases the symmetry breaking.

If a Lagrangian of the type (1) contained a term $\sim g\bar\psi\psi\varphi$, then on the left-hand side of Eq. (4) a term of the type $g^2\sigma(j^2)^{1/3}$ would appear, promoting symmetry restoration with an increase of j^2. This fact was pointed out in Ref. 7, where it was claimed that an increase of the fermion density j_0 leads to symmetry restoration in the theories with spontaneous symmetry breaking.

However, in the analysis of the symmetry behavior at $g^2\ll1$, the term $\sim g^2\sigma(j^2)^{1/3}$ can be neglected, compared with the term $-j^2/\sigma^3$ of Eq. (4). At $g^2\gg1$, terms of the type $g^2\sigma(j^2)^{1/3}$ can diminish the symmetry breaking, but the term $-j^2/\sigma^3$ prevents the symmetry restoration even at $g^2\gg1$. In any case at a sufficiently large density the term $-j^2/\sigma^3$, which appears in Eq. (4) due to the existence of neutral currents [i.e. due to the existence of the term $-e\bar\psi\gamma_\mu\psi A_\mu$ in (1)], becomes the leading term, and the density increase at large j^2 leads to an increase of the symmetry breaking. This result, which has been first obtained for the model (1),[8] has also been confirmed by the investigation of some other gauge theories with neutral currents.[9] In particular, it can easily be shown that in the Weinberg model of leptons[15] an equation for σ coincides exactly with Eq. (4) if the quantity j_μ in (4) corresponds to the neutrino current $\frac{1}{2}\langle\bar\psi\gamma_\mu(1+\gamma_5)\psi\rangle$. Therefore in both the Higgs model (1) and the Weinberg model[15] at a sufficiently large j^2,

$$\lambda\sigma^6=j^2.$$

It should be mentioned that since our results have been obtained in the tree approximation, they are gauge-invariant. To be more accurate, gauge invariance is a property of the physical quantities only. By performing a gauge transformation one can, e.g., make $\langle A_\mu\rangle$ equal to zero, and after this transformation the classical part φ_c of the field φ begins to rotate: $\varphi_c=\sigma\exp(-ieC_\mu x_\mu)$. Gauge invariance of the physical results in this case means, e.g., that Eq. (4) for $\sigma\equiv|\varphi_c|$ is gauge-invariant. This situation is completely analogous to that in the gauge-invariance problem of the superconductivity theory.[14]

It can easily be shown[8] that our approximation is reliable at λ, $e^2\ll1$, $\lambda\gtrsim e^4$. The last condition appears due to the fact that at $\lambda\ll e^4$, radiative corrections in e^2 prove to be of the same order as the terms that appear in the lowest approximation in λ.[5,6,16]

Let us now consider the case $\vec{j}=0$. As it follows from (4), the characteristic fermion density at which the parameter σ increases substantially is

$$j_0\sim\frac{\mu^3}{\lambda}\sim\sqrt{\lambda}\,\sigma^3(0),$$

where $\sigma(0)\equiv\sigma(j_\mu=0)$. To estimate the characteristic density j_0 we shall take $\sigma(0)\sim250$ GeV, as in the Weinberg model.[15] In this case $j_0\sim\sqrt{\lambda}\times10^{48}$ cm^{-3}. For $\sigma(0)\sim100$ MeV, $\mu\sim1$ GeV (strong interactions), $j_0\sim10^{39}$ cm^{-3}. The last value of fermion density is of the same order as the density in the cores of neutron stars.[17]

III. NONZERO TEMPERATURE

It is known that the unitary gauge used in the previous section (as well as the R gauges at $\xi\to0$) is rather inconvenient for an investigation of high-temperature symmetry behavior in gauge theories.[2,3,5,12] Therefore we shall carry out our calculations in the transverse gauge $\partial_\mu A_\mu=0$, in which

$$\varphi(x)=\frac{1}{\sqrt{2}}[\varphi_1(x)+i\varphi_2(x)+\sigma],$$
$$A_\mu(x)=B_\mu(x)+C_\mu.$$

The equations for σ and C_μ in this case are

$$\left\langle\frac{\delta L}{\delta\varphi_1}\right\rangle = -\sigma[\lambda\sigma^2-\mu^2+\lambda(3\langle\varphi_1{}^2\rangle+\langle\varphi_2{}^2\rangle) -e^2C_\mu{}^2-e^2\langle B_\mu{}^2\rangle] + 2e^2C_\mu\langle B_\mu\varphi_1\rangle\,,$$

$$\left\langle\frac{\delta L}{\delta B_\mu}\right\rangle = e^2C_\mu\sigma^2+e^2C_\mu(\langle\varphi_1{}^2\rangle+\langle\varphi_2{}^2\rangle) + 2e^2\sigma\langle B_\mu\varphi_1\rangle+e\langle\varphi_2\partial_\mu\varphi_1-\varphi_1\partial_\mu\varphi_2\rangle-ej_\mu\,. \tag{5}$$

Nondiagonal terms in (5) may turn out to be nonzero since at $j_\mu\neq 0$ the Lagrangian (1) contains the terms $e^2\sigma C_\mu B_\mu\varphi_1$ and $eC_\mu(\varphi_2\partial_\mu\varphi_1-\varphi_1\partial_\mu\varphi_2)$. However, at small j_μ (at $j^2\ll T^6$) the nondiagonal terms are small compared with the diagonal ones. On the other hand, the temperature corrections are appreciable only at $j^2\ll T^6$ (see below). Therefore one can neglect the nondiagonal terms in (5) in the investigation of the high-temperature effects. Let us suppose for simplicity that $\lambda\gg e^4$. In this case as in Ref. 5 it can be shown that all the temperature effects become appreciable only at $T\gg m_\varphi, m_B$. Since at $T\gg m_\varphi, m_B$,

$$\langle\varphi_i{}^2\rangle=-\tfrac{1}{3}\langle B_\mu{}^2\rangle=\tfrac{1}{12}T^2$$

(see, e.g., Refs. 4 and 5), Eqs. (5) in this case take the following form:

$$\sigma[\lambda\sigma^2-\mu^2-e^2C_\mu{}^2+\tfrac{1}{12}T^2(3e^2+4\lambda)]=0\,,$$

$$j_\mu-eC_\mu(\sigma^2+\tfrac{1}{6}T^2)=0\,.$$

From these equations it follows that

$$\sigma\left[\lambda\sigma^2-\mu^2-\frac{j^2}{(\sigma^2+\frac{1}{6}T^2)^2}+\frac{3e^2+4\lambda}{12}\right]=0\,. \tag{6}$$

At $T=0$ this equation coincides with Eq. (4), and at $j_\mu=0$ it coincides with the equation for σ obtained in Ref. 5 at $\lambda\gg e^4$. Equation (6) implies that an increase of temperature at a given j_μ leads to a decrease of the symmetry breaking, and at some $T=T_c$ the symmetry-breaking parameter σ vanishes. The critical temperature can easily be obtained by setting $\sigma=0$ in Eq. (6):

$$T_c{}^2=\frac{\mu^2}{3u}+\left(\left(\frac{\mu^2}{3u}\right)^3+\frac{18j^2}{u}+6\left\{\frac{j^2}{u}\left[\left(\frac{\mu^2}{3u}\right)^3+\frac{9j^2}{u}\right]\right\}^{1/2}\right)^{1/3} +\left(\left(\frac{\mu^2}{3u}\right)^3+\frac{18j^2}{u}-6\left\{\frac{j^2}{u}\left[\left(\frac{\mu^2}{3u}\right)^3+\frac{9j^2}{u}\right]\right\}^{1/2}\right)^{1/3}, \tag{7}$$

where $u=\frac{1}{12}(3e^2+4\lambda)$. From (7) it can be seen that, just as it has been claimed above, $T_c{}^6\gg j^2$. At $j^2=0$,

$$T_c{}^2=\frac{12\mu^2}{3e^2+4\lambda}\,.$$

This result coincides with the corresponding result of Refs. 2, 3, and 5 at $\lambda\gg e^4$. At $j^2\gg\mu^6/u^2$,

$$T_c{}^6=\frac{432j^2}{3e^2+4\lambda}\,. \tag{8}$$

In the Weinberg model an analogous investigation leads to the equation

$$\sigma\left[\lambda\sigma^2-\mu^2-\frac{j^2}{(\sigma^2+aT^2)^2}+b\frac{T^2}{12}\right]=0\,, \tag{9}$$

where j_μ is the neutrino current,

$$a=\frac{1}{6}\left[1+\frac{11}{6}\left(\frac{1}{1+\tan\theta}\right)^2\right],$$

$$b=4\lambda+\frac{3e^2}{\sin^2 2\theta}(1+2\cos^2\theta)\,,$$

θ is the Weinberg angle, and $\sin^2\theta\sim 0.35$. Numerically, $a\simeq\frac{1}{2}$, $b\simeq 4(\lambda+2e^2)$. Thus, in the Weinberg model at large j^2,

$$T_c{}^6=\frac{j^2}{\alpha}\,, \tag{10}$$

where $\alpha=\frac{1}{2}a^2b\simeq\frac{1}{12}(\lambda+2e^2)$.

IV. SYMMETRY BEHAVIOR IN THE EXPANDING UNIVERSE

According to the "hot" universe theory, the universe has been expanding and gradually cooling from the state with infinite temperature and density.[18] If the universe is charge-symmetric (i.e. if $j_0=0$), then as it follows from (9) there was no symmetry breaking in the Weinberg model at $t\to 0$, where t is the time from the beginning of the expansion.[5] Cosmological consequences of the possible symmetry restoration in the early universe have been discussed in detail in Refs. 5 and 6 (see also Ref. 19), and we shall not dwell on them here.

However, if at present the charge density j_0 is sufficiently large, then the symmetry breaking increased at $t\to 0$. To prove it, let us take the reference frame in which $\vec{j}=0$ (the rest frame of the substance). In the course of the expansion of the universe the value of j_0 has been decreasing as $t^{-3/2}$, while the temperature T has been decreasing as $t^{-1/2}$ (with some inessential corrections[18]). Therefore in the course of the expansion of the universe $j_0{}^2=\beta T^6$, where β is some constant. Let us consider the Weinberg model[15] and suppose that j_μ is a neutrino current. In this case, from (9) and (10) it follows that the symmetry has been restored at $t\to 0$ only if $\beta<\alpha$, and that $\sigma\to\infty$ at $t\to 0$ if $\beta>\alpha$. Let us now take into account that the photon density $n_\gamma=[2\zeta(3)/\pi^2]T^3\simeq 0.244\ T^3$.[20] Then the symmetry has been restored at $t\to 0$ only if

$$|j_0|<\frac{\sqrt{\alpha}\pi^2}{\zeta(3)}n_\gamma\simeq\left(\frac{\lambda+2e^2}{12}\right)^{1/2}\frac{\pi}{\zeta(3)}n_\gamma\,. \tag{11}$$

Let us suppose, for definiteness, that $\lambda \sim e^2 \sim 10^{-1}$; it is known experimentally that now $n_\gamma \sim 4\times 10^2$ cm^{-3}.[18] Then from (11) it follows that the symmetry has been restored in the early universe only if, at present,

$$|j_0| \lesssim 2\times 10^2 \text{ cm}^{-3}.$$

The density of electrons and baryons now is of the order of 10^{-5} cm^{-3}, and this is just the reason why in our investigation we have considered only the neutrino current $j_0 = n_\nu - n_{\bar\nu}$, where n_ν and $n_{\bar\nu}$ are the densities of neutrinos and antineutrinos, respectively. The value of j_0 may be, at present, very large. The strongest (but not quite reliable) constraint on j_0 follows from the theory of helium production in the universe: $j_0 \lesssim 10^3$ cm^{-3}.[18] This means that the phase transition with symmetry restoration could possibly not have taken place in the early universe, and that the solution of the problem of whether or not the symmetry was broken at $t\to 0$ depends essentially on the magnitude of the excess of neutrinos over antineutrinos in the universe at present.

The possibility that in the early stages of the evolution of the universe symmetry breaking did not vanish, but, on the contrary, infinitely increased at $t\to 0$, may have nontrivial consequences for cosmology. First of all, it would mean that at $t\to 0$ the masses of all particles except photons have been infinitely increasing. Moreover, it is not excluded that the photon is massless only because some symmetry is restored now, which was broken in the early universe owing to an infinite growth of j_0 at $t\to 0$. But this means that in the early universe even photons could be massive.

At a sufficiently large j_0 in the early universe, both masses of particles $m_{(\sigma)} \sim \sigma$ and temperature T were proportional to $j_0^{1/3}$, i.e., the quantity m/T was constant. Therefore the "hot" universe may appear always "effectively cold" for heavy particles (if the mass m of a particle is sufficiently large at present, then $m/T > 1$ at all temperatures). This fact may be connected also with the problem of the absence of free quarks in the universe. Namely, if the quarks were free at a sufficiently high temperature in the early universe, then even at present a large number of quarks should remain free, and they should have been detected, e.g., in cosmic rays.[18,21] This difficulty with free quarks exists also in a number of models with quark confinement, since if the quark confinement is connected with spontaneous symmetry breaking[22] and if the symmetry was restored in the early universe, then the quarks at $t\to 0$ actually were free. From our results now it follows that if there exists a sufficiently large excess of neutrinos over antineutrinos in the universe, then the confined quarks may never have been free, and the number of free quarks was always inhibited by an extremely small factor $\exp(-m/T)$. Analogously, the Pati-Salam quarks[23] may never have been free, and in this case the cosmological difficulties[24] associated with the Pati-Salam model[23] may also disappear.

One further result concerns the formation of domain walls, which should have taken place in the early universe after the discrete symmetry breaking in the theories with spontaneous breaking of CP invariance.[25] The possible existence of such domain walls drastically contradicts cosmological data,[19] and one could think that the absence of the domain walls in the universe implies that the theories with spontaneous breaking of CP invariance are unrealistic.[19] However, the domain walls can appear only as a result of the phase transition with symmetry breaking, and from our results it follows that this phase transition may well not have taken place in the early universe. Therefore, only the theories in which discrete symmetry breaking cannot be affected by an increase of neutrino density may be ruled out now by cosmological considerations.

All the above-mentioned points show the necessity for further, more detailed investigation of symmentry behavior in the "hot" universe within realistic theories of weak, strong, and electromagnetic interactions, taking into account the effects connected with a possible charge asymmetry of the universe. For a further analysis of this problem see Ref. 26.

ACKNOWLEDGMENTS

The author would like to thank Professor D. A. Kirzhnits and Professor Ya. B. Zel'dovich for their interest in this work, and also I. V. Krive, V. M. Pyzh, and E. M. Chudnovsky for many useful discussions. He also wishes to thank Professor Abdus Salam and Professor P. Budini as well as the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical physics, Trieste.

*On leave of absence from Lebedev Physical Institute, Moscow, U.S.S.R.

[1]D. A. Kirzhnits, Zh. Eksp. Teor. Fiz. Pis'ma Red. 15, 745 (1972) [JETP Lett. 15, 529 (1972)]; D. A. Kirzhnits and A. D. Linde, Phys. Lett. 42B, 471 (1972).

[2]S. Weinberg, Phys. Rev. D 9, 3357 (1974).

[3]L. Dolan and R. Jackiw, Phys. Rev. D 9, 3320 (1974).

[4]D. A. Kirzhnits and A. D. Linde, Zh. Eksp. Teor. Fiz.

67, 1263 (1974) [Sov. Phys.-JETP 40, 628 (1975)].

[5]D. A. Kirzhnits and A. D. Linde, Lebedev Physical Institute Report No. 101, 1974 (unpublished); D. A. Kirzhnits and A. D. Linde, ICTP Report No. IC/76/28 (unpublished).

[6]A. D. Linde, Lebedev Physical Institute Report No. 123, 1975 (unpublished); A. D. Linde, Zh. Eksp. Teor. Fiz. Pis'ma Red. 23, 73 (1976) [JETP Lett. 23, 64(1976)]; A. D. Linde, ICTP Report No. IC/76/27 (unpublished).

[7]B. J. Harrington and A. Yildiz, Phys. Rev. Lett. 33, 324 (1974); T. D. Lee and G. C. Wick, Phys. Rev. D 9, 2291 (1974); T. D. Lee and M. Margulies, *ibid.* 11, 1591 (1975); J. F. Bolzan and W. F. Palmer, *ibid.* 11, 2932 (1975).

[8]A. D. Linde, Lebedev Physical Institute Report No. 25, 1975 (unpublished).

[9]K. Sato and T. Nakamura, Prog. Theor. Phys. 55, 978 (1976); I. V. Krive, report (unpublished); I. V. Krive and E. M. Chudnovsky, Zh. Eksp. Teor. Fiz. Pis'ma Red. 23, 531 (1976).

[10]Abdus Salam and J. Strathdee, Nature 252, 569 (1974); Nucl. Phys. B90, 203 (1975).

[11]I. V. Krive, V. M. Pyzh, and E. M. Chudnovsky, Yad. Fiz. 23, 681 (1976).

[12]A. D. Linde, Lebedev Physical Institute Report No. 166, 1975 (unpublished); A. D. Linde, report (unpublished).

[13]A. D. Linde, Zh. Eksp. Teor. Fiz. Pis'ma Red. 19, 320 (1974) [JETP Lett. 19, 183 (1974)].

[14]P. G. De Gennes, *Superconductivity of Metals and Alloys* (Benjamin, New York, 1966).

[15]S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967).

[16]I. V. Krive and A. D. Linde, Lebedev Physical Institute Report No. 11, 1976 (unpublished).

[17]Ya. B. Zel'dovich and I. V. Novikov, *Theory of Gravity and Stars Evolution* (Nauka, Moscow, 1972).

[18]Ya. B. Zel'dovich and I. V. Novikov, *Construction and Evolution of the Universe* (Nauka, Moscow, 1975).

[19]Ya. B. Zel'dovich, I. Yu. Kobzarev, and L. B. Okun', Zh. Eksp. Teor. Fiz. 67, 3 (1974) [Sov. Phys.-JETP 40, 1 (1974)].

[20]L. D. Landau and E. M. Lifshitz, *Statistical Physics* (Pergamon, London, 1958).

[21]Ya. B. Zel'dovich, L. B. Okun', and S. B. Pikel'ner, Usp. Fiz. Nauk 87, 113 (1965) [Sov. Phys.-Usp. 8, 702 (1966)].

[22]W. A. Bardeen, M. S. Chanowitz, S. D. Drell, M. Weinstein, and T.-M. Yan, Phys. Rev. D 11, 1094 (1975); Y. Nambu, Phys. Rev. D 10, 4262 (1974); S. Mandelstam, Phys. Lett. 53B, 476 (1975); A. D. Linde, ICTP Report No. IC/76/33 (unpublished).

[23]J. C. Pati and Abdus Salam, Phys. Rev. D 8, 1240 (1973); 10, 275 (1974).

[24]L. B. Okun and Ya. B. Zel'dovich, Comments Nucl. Part. Phys. 6, 69 (1976).

[25]T. D. Lee, Rev. Mod. Phys. 47, 267 (1975).

[26]I. V. Krive, A. D. Linde, and E. M. Chudnovsky (unpublished).