Cosmological Production of Vector Bosons and Cosmic Microwave Background Radiation

D.B. Blaschke, S.I. Vinitsky, A.A. Gusev, V.N. Pervushin*1), and D.V. Proskurin

Joint Institute for Nuclear Research, Dubna, Moscow region, 141980 Russia

Abstract – The intensive cosmological creation of vector $W$, $Z$- bosons in the cosmological model with the relative units is considered. Field theoretical models are studied, which predict that the CMB radiation and the baryon matter in the universe can be products of decay and annihilation processes of these primordial bosons.

1. INTRODUCTION

Is modern theory able to explain the origin of observed matter in the Universe by its cosmological production from a vacuum [1-11]? As is well known, the answer to this question is associated with the problem of particle creation in the vicinity of a cosmological singularity. Thus far, it has been common practice to assume that the number of product pairs is by far insufficient for explaining the total amount of observed matter [7].

We recall that the cosmological creation of massive particles is calculated by going over to conformal variables [7], for which the limit of zero scale factor (point of a cosmic singularity) means the vanishing of masses. Vector bosons are the only particles of the Standard Model that have a singularity at zero mass [12, 13]. In this limit, the normalization of the wave function for massive vector bosons is singular in mass [12, 13]. The absence of the massless limit in the theory of massive vector bosons is well known [14]. In calculations in the lowest order of perturbation theory this leads to a divergence of the number of product longitudinal bosons [7, 11].

1)E-mail: pervush@thsun1.jinr.ru
There are two opinions concerning the removal of this singularity. In \[7, 15\] the divergence of the number of particles is removed by means of a standard renormalization of the gravitational constant. However, it is also indicated in the monograph of Grib et al. \[7\] that the number of product particles is determined by the imaginary part of loop Feynman diagrams; since, in quantum field theory, it is the real parts of these diagrams that are subjected to renormalization. This means that the above divergence of the number of particles does not belong to the class of divergences in quantum field theory that are removed by means of a conventional renormalization of physical quantities. Indeed, the physical origin of this divergence is that the problem of a cosmological creation of particles from a vacuum is treated within an idealized formulation. The point is that the quantum production of particles in a finite volume for a system featuring interaction and exchange effects may lead to a set of Bose particles having a specific statistical distribution with respect to energy such that it is able to ensure the convergence of the respective integral of the momentum distribution.

In the present study, we analyze physical conditions and models for which the number of product vector bosons maybe quite sufficient for explaining the origin of matter in the Universe. Such cosmological models include conformal cosmology \[16\], where conformal quantities of the general theory of relativity and of the Standard Model are defined as observables \[17\] for which there are relative reference units of intervals.

The ensuing exposition is organized as follows. Section 2 is devoted to discussing various versions of the formulation of the Cauchy problem for the cosmological production of vector particles in field theory. In Section 3 we study possible implications of such a production in the context of validating the temperature of cosmic microwave background radiation within the Standard Model, the baryon-antibaryon asymmetry of the Universe \[18, 19\],
and a small contribution of visible baryon matter \[20\] to the evolution of the Universe. In the Conclusion we discuss the results obtained by calculating the composition of matter in the Universe within the Standard Model.

2. **PROBLEM OF COSMOLOGICAL PARTICLE CREATION**

2.1. **Theory**

Let us consider cosmological particle creation in the conformally invariant version of the general theory of relativity \[9,21-24\]. We have

\[
S_{\text{tot}}[w|F] = S_D[w|e, Q] + S_{\text{SM}}[y_hw|f, e],
\]

where, for the action of the general relativity we take the Penrose-Chernikov-Tagirov action functional for a scalar field (dilaton) \(w\),

\[
S_D[w|e, Q] = \int d^4x \left[ |e|w^2 \left( \partial_\mu Q \partial^\mu Q - \frac{R(e)}{6} \right) + w \partial_\mu (|e|\partial^\mu) w \right],
\]

in the space specified by the interval

\[
ds^2 = (e_{\lambda\mu}dx^\mu)^2 = (e_{\Omega\mu}dx^\mu)^2 - (e_{\mu}dx^\mu)^2.
\]

Here \(e_{\lambda\mu}\) is Fock’s vierbein, \(R(e)\) is the curvature, and \(Q\) is an additional field that does not interact with matter \[\text{[III]}\] and which yields the observed regime of cosmological evolution. In the Standard Model action functional featuring the set of fields \(f\), the Higgs mass \(M_{\text{higgs}}\) is replaced by the dilaton multiplied by a constant \(y_h \sim 10^{-17}, (y_h w)\). The theory specified by action functional \([\Pi]\) is invariant under conformal transformations, including scale transformations for the set of all fields \([w|F]\) with the transformation parameter \(\Omega\),

\[
^{(n)}F_{\Omega} = (^{(n)}F) \times (\Omega)^n, \quad w_\Omega = \frac{w}{\Omega},
\]

where \((n)\) is a conformal weight. This invariance indicates that the action functional \([\Pi]\) involves an extra degree of freedom.
2.2. Absolute Variables

It is common practice to assume that the action of general theory of relativity and the Standard Model arises from the action functional as a consequence of choosing the “absolute” variables as

\[
(n)F_{(a)} = (n)F \times (w/\varphi_0)^n, \quad w_{(a)}(x^0, x^i) = \varphi_0,
\]

with the result that the dilaton \( w(x^0, x^i) \) is replaced the parameter \( \varphi_0 \) that is related to the Planck mass by the equation \( \varphi_0 = M_{Pl}(3/8\pi)^{1/2} \) and which did not appear in the original action functional. Upon the spontaneous scale-invariance breaking associated with this, the symmetry of the action functional under the transformations in becomes the symmetry of the physical variables in , which are invariant under the same scale transformations in . Owing to the above spontaneous breakdown of scale invariance, the extra degree of freedom characterized by a negative probability is removed from the action functional in , but, instead, the dimensional “absolute” Planck mass parameter \( M_{Pl} \) appears in the equations of motion. This parameter specifies initial data concerning the emergence of the Universe in the so-called Planck era. In the theory involving such a spontaneous breakdown of symmetry, the homogeneous approximation of the metric,

\[
e_{(a)0\mu}dx^\mu = dt, \quad e_{(a)ij\mu}dx^\mu = a(t)dx_i^j,
\]

for variables in leads to standard cosmological models including, the inflationary model , where the initial data of the Planck era are considered as the fundamental quantities of the equations of motion.

Within this approach, there arise problems of cosmological initial data, the horizon, time and energy, homogeneity, singularity, and the quantum wave function for the Universe, and attempts are made to solve these problems at the level of the homogeneous approximation via the inflationary expansion of absolute space .
In [22, 23], some arguments are adduced that indicate that, in all probability, all these problems, including the emergence of the Planck era, stem from an incorrect formulation of a spontaneous breakdown of the symmetry of (5) in eliminating degrees of freedom of negative probability from the theory specified by the action functional in (1).

We recall that, within a gauge theory, a formulation where all degrees of freedom that are characterized by a negative probability are removed prior to quantizing the theory being considered is referred to as a "fundamental method" [26, 27, 28], in contrast to a "heuristic method" [29], where all degrees of freedom are treated on equal footing. In [23], it was shown that, within relativistic string theory, these two methods lead to different spectra.

Experience gained in applying the fundamental-quantization method [26, 27] to string models [23, 31] and to non-Abelian theories [28] shows that, upon a spontaneous breakdown of the gauge symmetry of the theory being considered, there arise Goldstone modes that are associated with this symmetry breaking and which cannot be removed by any gauge transformations without significantly changing the physical content of the theory, including the spectrum of its elementary and collective excitations.

In [9, 16, 21], a spontaneous breakdown of the scale invariance of the theory being considered is formulated in terms of conformal variables, the Goldstone mode corresponding to this symmetry breaking being taken into account.

2) "The heuristic formulation" of a conformally invariant theory [30] leads to conformal anomalies, the Virasoro algebra and tachyons (particles for which the masses squared are negative), at the same time eliminating extra degrees of freedom with a negative probability at the level of the classical theory [31] leads to the Born-Infeld model featuring a positive energy spectrum free from tachyons.

3) In the non-Abelian theory of strong interactions, the analogous Goldstone mode leads to an extra contribution to the $\eta^0$-meson mass, while averaging over the topological degeneracy of initial data may lead to zero probabilities of the production of color states of quarks and gluons [28].
2.3. Conformal Variables

The choice of “relative” \((r)\) variables,

\[
(n)F_{(r)} = (n)F \times (w/\varphi(x^0))^n, \quad w_{(r)}(x^0, x^i) = \varphi(x^0), \quad (7)
\]

leaves the dilaton zero mode as a homogeneous variable \(\varphi(x^0)\) with a constant volume of three-dimensional hyperspace \([\text{11, 21]})\, V_{(r)} = \int d^3x |\bar{e}_{(r)}| \equiv \text{const},\]
in the reference frame specified by the embedding of a three-dimensional hyperspace into the four-dimensional manifold spanned by \(e_{00} = N, \, e_{ij} = \bar{e}_{ij}; \, e_{i0} = N_i\), where \(N\) and \(N_i\) are referred to the lapse function and the shift vector \([\text{32]}\), respectively. In this reference frame, an variable \(\varphi\) plays the role of a cosmic scale factor and an evolution parameter in the world space of the field variables \(\varphi|F\), while the canonical momentum defined as the derivative of the Lagrangian \(L_{\text{tot}}\) for the action functional \([\text{11]}\) with respect to the time derivative of the dilaton field \(\partial_0\varphi\),

\[
P_\varphi = \frac{\partial L_{\text{tot}}[\varphi|e_{(r)}]}{\partial(\partial_0\varphi)} = -2\partial_0\varphi \int d^3x \frac{|\bar{e}_{(r)}|}{N} \equiv -2V_{(r)} \frac{d\varphi}{d\eta}, \quad (8)
\]
is the localized energy of the Universe \([\text{23]}\); here, \(d\eta = N_0(x^0)dx^0\) is the invariant integral for the averaged lapse function \(N_0^{-1}(x^0) = \int d^3x |\bar{e}_{(r)}|N^{-1}/V_{(r)}\), while the bar over \(\bar{e}_{(r)}\), is, as we have seen above, denotes the spatial components of the vierbein for the constant volume \(V_{(r)} = \int d^3x |\bar{e}_{(r)}|\).

In terms of the conformal variables in \((7)\), the problems of the theory that are solved in terms of the absolute variables in \((5)\) with the aid of inflation are solved within the exact theory by means of the zero mode of the dilaton as the evolution parameter. In particular, the evolution of \(\varphi\) with respect to the time interval explains the problem of the horizon as a consequence of simultaneously varying particle masses and parameters of the system of fields over the entire space. The averaging of the exact equation \(\delta S_{\text{tot}}/\delta N = 0\) of the theory for the lapse function \(N\) in terms of the variables in \((7)\) over a
specific spatial volume housing measured objects yields the equation of the evolution of the Universe

\[ \varphi^2 = \rho, \]  

(9)

where \( \rho = \int d^3 x |e|[T^0_0 - \varphi^2(R^0_0 - R/2)], \) and \( T^0_0 \) \( R^0_0 \) being the components of the Einstein energy-momentum and the Ricci tensor, respectively.

We note that, in the exact theory specified by the action functional in (1), Eq. (9) is the analog of the Friedmann equation, which was derived in the approximation of homogeneity in the general theory of relativity. Thus, the approximation of a homogeneous universe coincides with the result obtained by averaging the exact equation \( \delta S_{tot}/\delta N = 0 \) over the volume. Solving Eq. (9), we arrive at an analog of the Friedman relation between the conformal time and density, \( \eta(\varphi_0, \varphi_I) = \pm \int_{\varphi_I}^{\varphi_0} d\varphi/\sqrt{\rho}. \)

Within the Hamiltonian formalism, where the time derivatives of the fields are replaced by the corresponding canonical momenta \( P_\varphi = -2V_{(r)}\varphi' \), the equation of the Universe evolution (9), which describes the evolution of the Universe, has the meaning of a Hamiltonian constraint, \( P_\varphi^2/4V_{(r)} = V_{(r)}\rho. \) The Hamiltonian \( V_{(r)}\rho \) as a generator of the conformal time evolution of fields can be represented as the sum of the Hamiltonian for a uniform scalar field, \( V_{(r)}\rho_Q, \) and the Hamiltonian for local field variables, \( H_{\text{field}}: V_{(r)}\rho = V_{(r)}\rho_Q + H_{\text{field}}, \) where \( \rho_Q \) is the density of the uniform scalar field.

In terms of the conformal variables in (7), the Planck mass as the “absolute” parameter of the equations of motion becomes a “random” current value of the field evolution parameter \( \varphi(x^0) \). Hence, in terms of the variables in (7) both the hypothesis of the Planck era and the problem of describing evolution from the Planck era \( 10^{-43}c \) on the basis of the inflationary model of the Universe lose physical meaning\(^4\).

\(^4\)The variables in (5) arise from (7) upon the substitution \((n)F_{(r)} = (n)F_{(u)}(\varphi/\varphi_0)^{-n} \). This transformation converts the variable \( \varphi \) with initial cosmological data \( \varphi(\eta = 0) = \varphi_I, H(\eta = 0) = H_I \) into its current value \( \varphi(\eta = \eta_0) = \varphi_0, \) with the result that one of the ordinary (random) values of the variable \( \varphi \) becomes, for the equations of motion, the absolute parameter \( \varphi_0 = \sqrt{3/(8\pi)}M_{Pl}, \) which is related to the Planck mass.
Within the conformal variables (7), there arises the problem of studying the quantum creation and evolution of a relativistic universe in the limit of infinitely low masses \( (\varphi(\eta) \to 0) \) and indefinitely high values of the Hubble parameter \( (H(\eta) \to \infty) \). The variables in (3) and those in (7) provide two different cosmologies and two different formulations of the problem of studying the origin of the Universe and matter.

2.4. Conformal Cosmology

In the approximation of homogeneity, the conformal variables in (7) correspond to directly measured quantities of observational cosmology. We recall that, in describing the cosmic evolution of the energy of photons emitted by atoms in a cosmic object, use is made of the conformal interval of photons \( (dx^i)^2 = dt^2/a^2(t) = d\eta^2 \) propagating along the light cone, \( ds^2 = 0 \), toward an observer. The redshift of spectral lines, which is a directly measurable quantity in observational cosmology, depends on the “conformal” time \( \eta = \eta_0 - r \) at the instant of photon emission by atoms of cosmic objects that occur at the “coordinate distance” \( r = \sqrt{(x^i)^2} \) from the Earth. In terms of the conformal coordinates, we find that the volume of the Universe does not increase, while all masses, including the Planck mass, are scaled by the cosmic factor \( a(\eta) \):

\[
m_{(r)}(\eta) = m_0 a(\eta), \quad [M_{\text{Pl}}\sqrt{3/8\pi}] a(\eta) = \varphi_0 a(\eta) = \varphi(\eta). \tag{10}
\]

In terms of the conformal time, which is associated with the observed time, the square-root regime of the evolution of the Universe in the era of primordial nucleosynthesis,

\[
a(t) = \tilde{a}(\eta) = \sqrt{1 + 2H_0(\eta - \eta_0)} = 1 - rH_0 + O(r^2) \tag{11}
\]

means that, in the era of chemical evolution, the Universe was filled with a free uniform scalar field (see Eq. (15) below) rather than with radiation. The
evolution according to Eq. (11) is prescribed by a rigid equation of state such
that pressure coincides with the energy density.

In [16], it was shown that, in terms of the conformal variables, data on
the dependence of the redshift on the distance to supernovae [17] and data
on nucleosynthesis correspond to the same rigid equation of state associated
with Eq. (11).

The identification of the conformal variables in (7) with observables quan-
tities leads to a different picture of the evolution of the Universe [11, 16, 21]
in relation to the analogous identification of the variables in (5) as is done
in conventional cosmology. The temperature history of a hot universe as
rewritten in terms of the conformal variables in (7) appears as the evolution
of elementary particle masses in a cold universe with a constant tempera-
ture of cosmic microwave background radiation. That the cosmic microwave
background radiation temperature $T_{CMBR}$ is independent of the redshift $z$
is, at first glance, in glaring contradiction with the observation [33] that
$6.0 \, \text{K} < T_{CMBR}(z = 2.3371) < 14 \, \text{K}$. In this observation, the tempera-
ture was deduced from the relative population of various energy levels (their
energies being denoted by $E_i$), which follows from Boltzmann statistics. How-
ever, the argument of the Boltzmann factors, which is equal to the ratio of
the temperature to the mass, features the same dependence on the factor $z$
in a cold universe as well [16]. Therefore, this ratio can be interpreted as the
$z$ dependence of energy levels (that is, mass) at a constant temperature. The
abundances of chemical elements are determined primarily by Boltzmann fac-
tors as well, which are dependent on functions of the mass-to-temperature
ratio, which are invariant under conformal transformations [34].

2.5. Initial Data of Quantum Cosmology

As a rule, quantum cosmology is defined as the homogeneous approxima-
tion of the metric,

\[ ds^2_{(r)} = [(d\eta)^2 - (dx^i)^2], \quad d\eta = N_0(x^0)dx^0, \quad (12) \]

with the shift function \( N_0(x^0) \) inheriting the symmetry group of the general theory of relativity in the form of invariance under reparametrizations of the coordinate time, \( x^0 \rightarrow \tilde{x}^0 = \tilde{x}^0(x^0) \). Cosmological models featuring this symmetry group, which were first described at a mathematically rigorous level by DeWitt, Wheeler, and Misner \[35, 36\] in the late 1960s, do not differ in any respect from the relativistic mechanics of a particle in the special theory of relativity. There is a direct correspondence between the Minkowski space of variables in the special theory of relativity and the space of field variables in the theory being considered, where the dilaton field \( \varphi \) plays the role of the time-like variable of Minkowski space.

In the particular case where the uniform scalar field \( Q(\eta) \) is dominant, we arrive at a simple cosmological model of the Universe \[11\]; that is,

\[ S_{\text{univ}} = V_r \int \frac{dx^0}{N_0} \left[ -\left( \frac{d\varphi}{dx^0} \right)^2 + \varphi^2 \left( \frac{dQ}{dx^0} \right)^2 \right] = \int \left\{ -P_\varphi \frac{d\varphi}{dx^0} + P_Q \frac{dQ}{dx^0} + N_0V_r \left[ (P_\varphi/2V_r)^2 - (P_Q/2\varphi V_r)^2 \right] \right\}, \]

where \( P_Q = 2V_r \varphi^2 Q', \quad P_\varphi = 2V_r \varphi' \) are canonical momenta. A variation of the action functional with respect to the shift function \( N(x^0) \) leads to a constraint equation for these two momenta,

\[ P_\varphi^2 - P_Q^2/\varphi^2 = 0 \quad \Rightarrow \quad P_\varphi = \pm P_Q/\varphi, \quad (14) \]

its solution being

\[ P_Q = 2V_r H_I \varphi_I^2 = \text{const}, \quad \varphi^2 = \varphi_I^2(1 + 2H_I\eta), \quad (15) \]

where \( \varphi_I^2 H_I = P_Q/2V_r \) is an integral of the motion. As was shown in \[16\], the resulting evolution law \[15\] for the scale factor is compatible with the evolution of supernovae in terms of conformal variables \[17\].
Upon the quantization of the theory specified by the action functional \( S(\varphi) \), the Wheeler-DeWitt equation for the wave function \( \Psi \),

\[
\left[ \hat{P}_\varphi^2 - \frac{\hat{P}_Q^2}{\varphi^2} \right] \Psi = 0
\]
arises as the direct analogy of the Klein–Gordon equation in the quantum general theory of relativity. Like that solution to the Klein-Gordon equation for a relativistic particle which describes the creation and annihilation of positive-energy particles, the solution

\[
\Psi = A_{\varphi \geq 0}^+ \Psi^+ [P_Q|\varphi] e^{iP_Q(Q-Q_I)} \theta(\varphi - \varphi_I) + \\
A_{\varphi \leq 0}^- \Psi^- [P_Q|\varphi] e^{-iP_Q(Q-Q_I)} \theta(-\varphi)
\]
to the Wheeler-DeWitt equation depends on the initial data \( Q_I \) and \( \varphi_I \). In order to get rid of negative energies and to create a stable quantum system, a causal quantization is postulated in quantum field theory in such a way that positive-energy excitations move in the forward direction along the time axis, while negative-energy excitations move in the backward direction with respect to time. The analogous interpretation of the coefficient \( A^+ \) as the creation operator for the Universe, and the coefficient \( A^- \) as the annihilation operator for the anti-Universe solves the problem of a cosmic singularity of the Universe at positive “energy”, since, for positive energies, the wave function does not involve the singularity point \( \varphi = 0 \); this singularity appears in the negative-“energy” wave function, which is treated as the amplitude of the probability for the annihilation of the anti-Universe.

The quantum general theory of relativity loses the geometric interval of time and information about how the metric depends on the time interval-in particular, it loses the Hubble law describing the dependence of the scale on the time interval [see Eqs. (15)]. In [22], it was proposed to make a canonical transformation (known as the Levi-Civita transformation) from the original variables to a new world space of variables. In terms of these variables, the
cosmic scale (dilaton) becomes a geometric interval of time with cosmic initial
data \( \varphi(\eta = 0) = \varphi_I, \ H(\eta = 0) = H_I \) in (15), which are random values of variables fitted to experimental data.

In this case, the conformal variables in (17) naturally lead to the concept of particles [9], which has been used and is being presently used in almost all of the studies devoted to the cosmological creation of particles [7].

\[
\text{2.6. Definition of a Particle in Quantum Field Theory}
\]

In quantum field theory, the concept of a particle can be associated only with those field variables that are characterized by a positive probability and a positive energy. Negative energies are removed by causal quantization, according to which the creation operator at a negative energy is replaced by the annihilation operator at the respective positive energy. All of the variables that are characterized by a negative probability can be removed according to the scheme of fundamental operator quantization [26]. The results obtained by applying the operator-quantization procedure to massive vector fields in the case of the conformal flat metric (12) are given in [9, 11, 13].

In order to determine the evolution law for all fields \( v \), it is convenient to use the Hamiltonian form of the action functional for their Fourier components \( v^I_k = \int d^3 x e^{i k \cdot x} v^I(x) \); that is,

\[
S_{\text{tot}} = \int_{x_0^I}^{x_2^I} dx^0 \left\{ \sum_k \left[ P_{\perp k} \partial_0 v_{\perp k} + P_{\parallel k} \partial_0 v_{\parallel k} \right] - P_a \partial_0 a + N_0 \left[ \frac{P_a^2}{4 V(r) \varphi_0^2} - V(r) \rho_{\text{tot}} \right] \right\},
\]

where \( P_{\perp k}, P_{\parallel k} \) are the canonical momenta for, respectively, the transverse and the longitudinal component of vector bosons and \( \rho_{\text{tot}} \) is the sum of the conformal densities of the scalar field obeying the rigid equation of state and the vector field,

\[
\rho_{\text{tot}}(a) = \frac{\varphi_0^2 H_0^2}{a^2} + \rho_v(a),
\]
\[ \rho_v(a) = V_{(v)}^{-1}(H^\perp + H^\parallel), \quad (18) \]

\[ H^\perp \quad H^\parallel \text{ being the Hamiltonians for a free field,}^{5) \]

\[ H^\perp = \sum_k \frac{1}{2} \left[ p_k^\perp + \frac{\omega^2}{M_v} v_k^\perp \right]^2, \quad (19) \]

\[ H^\parallel = \sum_k \frac{1}{2} \left[ \left( \frac{\omega(a,k)}{M_v} \right)^2 p_k^\parallel + (M_v a)^2 v_k^\parallel \right]. \]

Here, the dispersion relation has the form \( \omega(a,k) = \sqrt{k^2 + (M_v a)^2} \); for the sake of brevity, we have also introduced the notation \( p_k^\parallel \equiv p_k \cdot p_k^\perp \).

Within the reparametrization-invariant models specified by action functionals of the type in (16) with the Hamiltonians in (19), the concepts of an observable particle and of cosmological particle creation were defined in [9]. We will illustrate these definitions by considering the example of an oscillator with a variable energy. Specifically, we take its Lagrangian in the form

\[ \mathcal{L} = p_v \partial_0 v - N_0 \left[ \frac{1}{2} p_v^2 + \omega^2 v^2 - \omega \right] + \rho_0 (N_0 - 1). \quad (20) \]

The quantity \( H_v = [p_v^2 + \omega^2 v^2]/2 \) has the meaning of a “conformal Hamiltonian” as a generator of the evolution of the fields \( v \) and \( p_v \) with respect to the conformal-time interval \( d\eta = N_0 dx \), where the shift function \( N_0 \) plays the role of a Lagrange multiplier. The equation for \( N_0 \) introduces the density \( \rho_0 = H_v - \omega/2 \) in accordance with its definition adopted in the general theory of relativity. In quantum field theory [3, 9], the diagonalization of precisely the conformal Hamiltonian

\[ H_v = \frac{1}{2} [p_v^2 + \omega^2 v^2] = \omega \left[ \hat{N}_{\text{part}} + \frac{1}{2} \right] \quad (21) \]

specifies both the single-particle energy \( \omega = \sqrt{k^2 + (M_v a(\eta))^2} \) and the particle-number operator

\[ \hat{N}_{\text{part}} = \frac{1}{2\omega} [p_v^2 + \omega^2 v^2] - \frac{1}{2} \quad (22) \]

---

5) In quantum field theory, observables that are constructed from the above field variables form the Poincaré algebra [13, 20, 28]. Therefore, such a formulation, which depends on the reference frame used, does not contradict the general theory of irreducible and unitary transformations of the relativistic group [37].
with the aid of the transition to the symmetric variables \( p \) and \( q \) defined as

\[
P_v = \sqrt{\omega}p = i\sqrt{\frac{\omega}{2}}(a^+ - a), \quad v = \sqrt{\frac{1}{\omega}}q = \sqrt{\frac{1}{2\omega}}(a^+ + a). \tag{23}
\]

In terms of the symmetric variables \( p, q \) the particle-number operator takes form

\[
\hat{N}_{\text{part}} = \frac{1}{2}[p^2 + q^2] - \frac{1}{2} = a^+a. \tag{24}
\]

Upon going over to these variables in the Lagrangian in \((20)\), we arrive at

\[
\mathcal{L} = p\partial_0q - pq\partial_0\Delta^\perp - N_0\omega[\hat{N}_{\text{part}} + 1/2], \tag{25}
\]

where \( \partial_0\Delta^\perp = \partial_0\omega/2\omega \) and where there appears sources of cosmic particle creation in the form \( pq = i[(a^+)^2 - a^2]/2 \). Here, we give a derivation of these sources for transverse fields, whereas, for longitudinal fields [see Eq.\((19)\)], the analogous diagonalization of the Hamiltonian leads to the factor \( \partial_0\Delta^\parallel = \partial_0\varphi/\varphi - \partial_0\omega/2\omega \).

In order to diagonalize the equations of motion in terms of the mentioned new variables, it is necessary to apply, to the phase space, the rotation transformation

\[
p = p_\theta \cos \theta + q_\theta \sin \theta, \quad q = q_\theta \cos \theta - p_\theta \sin \theta \tag{26}
\]

and the squeezing phase space transformation

\[
p_\theta = \pi e^{-r}, \quad q_\theta = \xi e^+r. \tag{27}
\]

As a result, the Lagrangian in \((25)\) assumes the form

\[
\mathcal{L} = \pi\partial_0\xi + \pi\xi[\partial_0r - \partial_0\Delta \cos 2\theta] +
\]

\[
+ \frac{\pi^2}{2}e^{-2r}[\partial_0\theta - N_0\omega - \partial_0\Delta \sin 2\theta] + \frac{\xi^2}{2}e^{2r}[\partial_0\theta - N_0\omega + \partial_0\Delta \sin 2\theta].
\]

The equations of motion that are obtained from this Lagrangian,

\[
\xi' + \xi[r' - \Delta' \cos 2\theta] + \pi e^{-2r}[\partial_0\theta - N_0\omega - \partial_0\Delta \sin 2\theta] = 0, \tag{29}
\]
\[ \pi' - \pi [r' - \Delta' \cos 2\theta] - \xi 2e^{2r} [\partial_0 \theta - N_0 \omega + \partial_0 \Delta \sin 2\theta] = 0, \quad (30) \]
take a diagonal form,
\[ \xi' + \omega_b \pi = 0, \quad -\pi' + \omega_b \xi = 0, \quad (31) \]
if \( \omega_b = e^{-2r}[\omega - \theta' - \Delta' \sin 2\theta] \) and if the rotation parameter \( \theta \) and the squeezing parameter \( r \) satisfy the equations
\[ [\theta' - \omega] \sinh 2r = -\Delta' \sin 2\theta \cosh 2r, \quad r' = \Delta' \cos 2\theta. \quad (32) \]
By solving these equations, we can find the time dependence of the number of particles produced in cosmic evolution (24)
\[ \hat{N}_{\text{part}} = \cosh 2r - \frac{1}{2} + \cosh 2r \hat{N}_{\text{part}} + \sinh 2r \frac{\pi^2 - \xi^2}{2}, \quad (33) \]
where \( \hat{N}_{\text{part}} = [\pi^2 + \xi^2 - 1]/2 = b^+ b \) is the number of quasiparticles defined as variables that diagonalize the equation of motion. Since the equation of motion is diagonal, the number of quasiparticles is an integral of the motion, that is, a quantum number that characterizes the quantum state of the Universe. One of these states is the physical vacuum state \( |0\rangle_{sq} \) of quasiparticles (that is, the squeezed vacuum, which is labelled with the subscript “sq” in order to distinguish it from the vacuum of ordinary particles),
\[ b_s |0\rangle_{sq} = 0 \quad (b = \frac{1}{\sqrt{2}}[\xi + i\pi]). \quad (34) \]
In the squeezed-vacuum state, the number of quasiparticles is equal to zero
\[ \langle 0 | \hat{N}_{\text{part}} | 0 \rangle_{sq} = 0. \quad (35) \]
In this case, the expectation value of the particle-number operator (33) in the squeezed-vacuum state is
\[ \langle 0 | \hat{N}_{\text{part}} | 0 \rangle_{sq} = \frac{\cosh(2r(\eta)) - 1}{2} = \sinh^2 r(\eta). \quad (36) \]
\(^6\)These equations for transverse and longitudinal bosons coincide completely with the equations for the coefficients of the Bogolyubov transformation \( b = \alpha a + \beta a^+ \), \( \alpha' - i\omega \alpha = \Delta' \beta \), derived by using the Wentzel-Kramers-Brillouin method in [7], see Eqs. (9.68) and (9.69) in [7] on page 185 in the Russian edition of this monograph, where it is necessary to make the change of variables specified by the equations \( \Delta' = \frac{\omega_{\frac{3}{2}}}{\omega^{(1)}}, \alpha^* = \exp[i\theta - i \int dp \omega] \cosh r, \beta = \exp[-i\theta + i \int dp \omega] \sinh r. \)
The time dependence of this quantity is found by solving the Bogolyubov equation (32). The origin of the Universe is defined as the conformal-time instant $\eta = 0$, at which the number of particles and the number of quasi-particles are both equal to zero. The resulting set of Eqs. (32) becomes closed upon specifying the equation of state and initial data for the number of particles. In just the same way, the number of particles characterized by an arbitrary set of quantum numbers $\varsigma$,

$$N_\varsigma(\eta) = \langle 0 | \hat{N}_\varsigma | 0 \rangle_{sq} = \sinh^2 r_\varsigma(\eta), \quad (37)$$

and produced from the “squeezed” vacuum by the time instant $\eta$ can be determined by solving an equation of the type in (32).

Thus, just the conformal quantities of the theory, such as the energy $\omega_k = \sqrt{k^2 + M^2 a^2}$, the number particles $\hat{N}_{\text{part}}$, the conformal density

$$\rho_\nu = \sum_k \langle 0 | \hat{N}_{k, \text{part}} | 0 \rangle_{sq} \omega_k / V(r)$$

that are associated with observables, in just the same way as the conformal time in observational cosmology is associated with the observed time [16].

3. PHYSICAL IMPLICATIONS

3.1. Calculation of the Distribution Function

Let us consider the example where the above set of equations is solved for the evolution law (11) in the case of the rigid equation of state,

$$a(\eta) = a_I \sqrt{1 + 2H_I \eta} \quad (a_I^2 H_I = H_0),$$

where $a_I = a(0)$ and $H_I$ are initial data at the matter-production instant.

We introduce the dimensionless variables of time $\tau$ and momentum $x$ and the coefficient $\gamma_\nu$ according to the formulas

$$\tau = 2\eta H_I = \eta / \eta_I, \quad x = \frac{q}{M_I}, \quad \gamma_\nu = \frac{M_I}{H_I}, \quad (38)$$
where $M_I = M_v(\eta = 0)$ are initial data for the mass. In terms of these variables, the single-particle energy has the form $\omega_v = H_I \gamma_v \sqrt{1 + \tau + x^2}$.

The Bogolyubov equations (32) can be represented as

\[
\left[ \frac{\gamma_v}{2} \sqrt{(1 + \tau) + x^2} - \frac{d\theta_v^\|}{d\tau} \right] \text{th}(2r_v^\|) = -\left[ \frac{1}{2(1 + \tau)} - \frac{1}{4[(1 + \tau) + x^2]} \right] \sin(2\theta_v^\|),
\]

\[
\frac{d}{d\tau} r_v^\| = \left[ \frac{1}{2(1 + \tau)} - \frac{1}{4[(1 + \tau) + x^2]} \right] \cos(2\theta_v^\|),
\]

\[
\left[ \frac{\gamma_v}{2} \sqrt{(1 + \tau) + x^2} - \frac{d\theta_v^\perp}{d\tau} \right] \text{th}(2r_v^\perp) = -\left[ \frac{1}{4[(1 + \tau) + x^2]} \right] \sin(2\theta_v^\perp),
\]

\[
\frac{d}{d\tau} r_v^\perp = \left[ \frac{1}{4[(1 + \tau) + x^2]} \right] \cos(2\theta_v^\perp). \quad (39)
\]

We solved these equations numerically at positive values of the momentum $x = q/M_I$, considering that, for $\tau \to +0$, the asymptotic behavior of the solutions is given by $r(\tau) \to \text{const} \cdot \tau$ and $\theta(\tau) = O(\tau)$. The distributions of longitudinal $\mathcal{N}^\|_v(x, \tau)$ and transverse $\mathcal{N}^\perp_\tau(x, \tau)$ vector bosons are given in the Figure 1. for the initial data $H_I = M_I \ (\gamma_v = 1)$.

From the Figure 1, it can be seen that, for $x > 1$, the longitudinal component of the boson distribution is everywhere much greater than than the transverse component, this demonstrating a more copious cosmological creation of longitudinal bosons in relation to transverse bosons. A slow decrease in the longitudinal component as a function of momentum leads to a divergence of the integral for the density of product particles [2]:

\[
n_v(\eta) = \frac{1}{2\pi^2} \int_0^\infty dq q^2 \left[ \mathcal{N}^\|_v(q, \eta) + 2\mathcal{N}^\perp_\tau(q, \eta) \right] \to \infty. \quad (40)
\]

### 3.2. Thermalization of Bosons

The divergence of the integral (40) stems from idealizing the problem of the production of a pair of particles in a finite volume for a system where there
are simultaneous interactions associated with the removal of fields having a negative probability and where identical particles affect one another (so-called exchange effects). In this case, it is well known [38], that one deals with the production not a pair but a set of Bose – particles, which acquires, owing to the aforementioned interactions, the properties of a statistical system. As a model of such a statistical system, we consider here a degenerate Bose-Einstein gas, whose distribution function has the form (we use the system of units where the Boltzmann constant is $k_B = 1$)

$$
\mathcal{F}(T_v, q, M_v(\eta), \eta) = \left\{ \exp \left[ \frac{\omega_v(\eta) - M_v(\eta)}{T_v} \right] - 1 \right\}^{-1},
$$

(41)

where $T_v$ is the boson temperature. We set apart the problem of theoretically validating such a statistical system and its thermodynamic exchange, only assuming fulfillment of specific conditions ensuring its existence. In particular, we can introduce the notion of the temperature $T_v$ only in an equilibrium system. A thermal equilibrium is thought to be stable if the time within which the vector-boson temperature $T_v$ is established, that is, the relaxation
time \[ \eta_{\text{rel}} = \left[ n(T_v) \sigma_{\text{scat}} \right]^{-1} \] (42)

(expressed in terms of their density \( n(T_v) \) and the scattering cross section \( \sigma_{\text{scat}} \sim 1/M_I^2 \)), does not exceed the time of vector-boson-density formation owing to cosmological creation, the latter time being controlled by the primordial Hubble parameter \( \eta_v = 1/H_I \). From formula (42) it follows, that the particle-number density is proportional to the product of the Hubble parameter and the mass squared, that is an integral of the motion in the present example:

\[ n(T_v) = n(T_v, \eta_v) \simeq C_H H_I M_I^2, \] (43)

where \( C_H \) is a constant. The expression for the density \( n(T_v, \eta) \) in Eq. (43) assumes the form

\[ n_v(T_v, \eta) = \frac{1}{2\pi^2} \int_0^\infty dq q^2 \mathcal{F}(T_v, q, M(\eta), \eta) \left[ N^\parallel(q, \eta) + 2N^\perp(q, \eta) \right]. \] (44)

Here, the probability of the production of a longitudinal and a transverse boson with a specific momentum in an ensemble featuring exchange interaction is given (in accordance with the multiplication law for probabilities) by the product of two probabilities, the probability of their cosmological creation, \( \mathcal{N}^\parallel, \mathcal{N}^\perp \) and the probability of a single-particle state of vector bosons obeying the Bose-Einstein distribution (41).

A dominant contribution to the integral (44) from the region of high momenta (in the above idealized analysis disregarding the Boltzmann factor, this resulted in a divergence) implies the relativistic temperature dependence of the density,

\[ n(T_v, \eta_v) = C_T T_v^3, \] (45)

where \( C_T \) is a coefficient. A numerical calculation of the integral (44) for the values \( T_v = M_I = H_I \), which follow from the assumption about the choice of initial data \( (C_T = C_H) \), reveals that this integral (44) is weakly dependent on
time in the region $\eta \geq \eta_v = H_I^{-1}$ and, for the constant $C_T$, yields the value
\[ C_T = \frac{n_v}{T_v^3} = \frac{1}{2\pi^2} \left\{ [1, 877] || + 2[0, 277] \perp = 2,431 \right\}, \tag{46} \]
where the contributions of longitudinal and transverse bosons are labeled with the superscripts $(||, \perp)$, respectively.

On the other hand, the lifetime $\eta_L$ of product bosons in the early Universe in dimensionless units $\tau_L = \eta_L/\eta_I$, where $\eta_I = (2H_I)^{-1}$, can be estimated by using the equation of state $a^2(\eta) = a_I^2(1 + \tau_L)$ and the $W$-boson lifetime within the Standard Model. Specifically, we have
\[ 1 + \tau_L = \frac{2H_I \sin^2 \theta(W)}{\alpha_{\text{QED}} M_W(\eta_L)} = \frac{2\sin^2 \theta(W)}{\alpha_{\text{QED}} \gamma_v \sqrt{1 + \tau_L}}, \tag{47} \]
where $\theta(W)$ is the Weinberg angle, $\alpha_{\text{QED}} = 1/137$ is the fine-structure constant, and $\gamma_v = M_I/H_I \geq 1$.

From the solution to Eq. (47),
\[ \tau_L + 1 = \left( \frac{2\sin^2 \theta(W)}{\gamma_v \alpha_{\text{QED}}} \right)^{2/3} \simeq \frac{16}{\gamma_v^{2/3}} \tag{48} \]
it follows that, at $\gamma_v = 1$, the lifetime of product bosons is an order of magnitude longer than the Universe relaxation time:
\[ \tau_L = \frac{\eta_L}{\eta_I} \simeq \frac{16}{\gamma_v^{2/3}} - 1 = 15. \tag{49} \]

Therefore, we can introduce the notion of the vector-boson temperature $T_v$, which is inherited by the final vector boson decay products (photons). According to currently prevalent concepts, these photons form cosmic microwave background radiation in the Universe. Indeed, suppose that one photon comes from the annihilation of the products of $W^\pm$-boson decay and that the other comes from $Z$-bosons. In view of the fact that the volume of the Universe is constant within the evolution model being considered, it is then natural to expect that the photon density coincides with the boson density [11]
\[ n_\gamma = T_v^3 \frac{1}{\pi^2} \{2.404\} \simeq n_v. \tag{50} \]
On the basis of (43), (45), (46) and (50) we can estimate the temperature $T_\gamma$ of cosmic microwave background radiation arising upon the annihilation and decay of $W^+$ and $Z$-bosons:

$$T_\gamma \simeq \left[ \frac{2.431}{2.404 \cdot 2} \right]^{1/3} T_v = 0.8 T_v,$$

(51)

taking into account that the temperature of vector-bosons $T_v = [H_I M_I^2]^{1/3}$ is an invariant quantity in the described model. This invariant can be estimated at

$$T_v = [H_I M_I^2]^{1/3} = [H_0 M_W^2]^{1/3} = 2.73/0.8 K = 3.41 K$$

(52)

which is a value that is astonishingly close to the observed temperature of cosmic microwave background radiation. In the present case, this directly follows, as is seen from the above analysis of our numerical calculations, from the dominance of longitudinal vector bosons with high momenta and from the fact that the relaxation time is equal to the inverse Hubble parameter. The inclusion of physical processes, like the heating of photons owing to electron-positron annihilation $e^+ e^- \ [40]$ amounts to multiplying the photon temperature (51) by $(11/4)^{1/3} = 1.4$ therefore, we have

$$T_\gamma(e^+ e^-) \simeq (11/4)^{1/3} 0.8 T_v = 2.77 K.$$ 

(53)

We note that, in other models $[41]$, the fluctuations of the product-particle density are related to primary fluctuations of cosmic microwave background radiation $[42]$.

3.3. Inverse Effect of Product Particles on the Evolution of the Universe

The equation of motion $\phi'^2(\eta) = \rho_{tot}(\eta)$, with the Hubble parameter defined as $H = \phi'/\phi$, means that, at any instant of time, the energy density in the Universe is equal to the so-called critical density; that is

$$\rho_{tot}(\eta) = H^2(\eta) \phi^2(\eta) \equiv \rho_{cr}(\eta).$$
The dominance of matter obeying the extremely rigid equation of state implies the existence of an approximate integral of the motion in the form

\[ H(\eta)\varphi^2(\eta) = H_0\varphi_0^2 . \]

On this basis, we can immediately find the ratio of the product-vector-boson energy, \( \rho_v(\eta_I) \sim T^4 \sim H_I^4 \sim M_I^4 \), to the density of the Universe in the extremely rigid state, \( \rho_{\text{tot}}(\eta_I) = H_I^2\varphi_I^2 \),

\[
\frac{\rho_v(\eta_I)}{\rho_{\text{tot}}(\eta_I)} = \frac{M_I^2}{\varphi_I^2} = \frac{M_W^2}{\varphi_0^2} = y_v^2 = 10^{-34} . \tag{54}
\]

This value indicates that the inverse effect of product particles on the evolution of the Universe is negligible.

The primordial mesons before their decays polarize the Dirac fermion vacuum and give the baryon asymmetry frozen by the CP – violation, so that \( n_b/n_\gamma \sim X_{CP} \sim 10^{-9} \) and \( \Omega_b \sim \alpha_{\text{qed}}/\sin^2 \theta(W) \sim 0.03. \)

### 3.4. Baryon-antibaryon Asymmetry of Matter in the Universe

In each of the three generations of leptons (,\( \mu, \tau \)) and color quarks, we have four fermion doublets-in all, there are \( n_L = 12 \) of them. Each of 12 fermion doublets interacts with the triplet of non-Abelian fields \( A^1 = (W^(-) + W^+) / \sqrt{2}, \ A^2 = i(W^(-) - W^+) / \sqrt{2}, \) and \( A^3 = Z/\cos \theta_W \), the corresponding coupling constant being \( g = e/\sin \theta_W \).

It is well known that, because of a triangle anomaly, W- and Z- boson interaction with lefthanded fermion doublets \( \psi_{L}^{(i)}, i = 1, 2, ..., n_L, \) leads to a nonconservation of the number of fermions of each type (i) \[43,44\],

\[
\partial_{\mu}j_{L,\mu}^{(i)} = \frac{1}{32\pi^2} \text{Tr} \hat{F}_{\mu\nu} \hat{j}_{\mu\nu} , \tag{55}
\]

where \( \hat{F}_{\mu\nu} = -iF_{\mu\nu}g_W\tau_a/2 \) is the strength of the vector fields, \( F_{\mu\nu} = \partial_{\mu}A_{\nu}^a - \partial_{\nu}A_{\mu}^a + g\epsilon^{abc}A_{\mu}^bA_{\nu}^c \).
Taking the integral of the equality in (55) with respect to the four-dimensional variable \(x\), we can find a relation between the change \(\Delta F^{(i)} = \int d^4 x \partial_\mu j^{(i)}_\mu\) the fermion number \(F^{(i)} = \int d^3 x j^{(i)}_0\) and the Chern-Simons functional \([10]\), \(N_{CS} = \frac{1}{32\pi^2} \int d^4 x \text{Tr} \hat{F}_{\mu\nu}^* \hat{F}_{\mu\nu}\):

\[
\Delta F^{(i)} = N_{CS} \neq 0, \quad i = 1, 2, \ldots, n_L. \tag{56}
\]

The equality in (56) is considered as a selection rule – that is, the fermion number changes identically for all fermion types: \(N_{CS} = \Delta L^e = \Delta L^\mu = \Delta L^\tau = \Delta B/3\); at the same time, the change in the baryon charge \(B\) and the change in the lepton charge \(L = L^e + L^\mu + L^\tau\) are related to each other in such a way that \(B - L\) is conserved, while \(B + L\) is not invariant. Upon taking the sum of the equalities in (56) over all doublets, we obtain \(\Delta (B + L) = 12 N_{CS}\).

We can evaluate the expectation value of the Chern-Simons functional (56) (in the lowest order of perturbation theory in the coupling constant) in the Bogolyubov vacuum \(b|0 >_{sq} = 0\). Specifically, we have

\[
N_{CS} = N_W + N_Z \equiv - \sum_{v=W,Z} \eta_{Lv} \int d\eta \int \frac{d^3 x}{32\pi^2} \text{sq} \langle 0 | \text{Tr} \hat{F}_{\mu\nu}^* \hat{F}_{\mu\nu} | 0 \rangle_{sq}, \tag{57}
\]

where \(\eta_{LW}\) and \(\eta_{LZ}\) are the W- and the Z-boson lifetime, and \(N_W\) and \(N_Z\) are the contributions of primordial W and Z bosons, respectively. The integral over the conformal spacetime bounded by three-dimensional hypersurfaces \(\eta = 0\) and \(\eta = \eta_L\) is given by

\[
N_v = \beta_v \frac{V_0}{2} \int_0^{\eta_{Lv}} d\eta \int_0^\infty dk |k|^3 R_v(k, \eta)
\]

where \(v = W, Z\);

\[
\beta_W = \frac{4\alpha_{QED}}{\sin^2 \theta_{(W)}}, \quad \beta_Z = \frac{\alpha_{QED}}{\sin^2 \theta_{(W)} \cos^2 \theta_{(W)}}, \tag{58}
\]

and the rotation parameter

\[
R_v = - \sinh(2r) \sin(2\theta)
\]
is specified by relevant solutions to the Bogolyubov equations \((39)\). Upon a numerical calculation of this integral, we can estimate the expectation value of the Chern-Simons functional in the state of primordial bosons. Primordial fluctuation of the baryon number

\[
\frac{n_b(\eta)}{n_b(\eta_L)} = \frac{\int d\kappa^2 \int d\eta_R^W \frac{\eta}{0} [4 \cos^2 \theta_{(W)} R_W + R_Z]}{\int d\kappa^2 [4 \cos^2 \theta_{(W)} \int d\eta_R^W + \int d\eta_R^Z]}. \tag{59}
\]

At the vector-boson-lifetime values of \(\tau_L^W = 15, \tau_L^Z = 30\), this yields the following result at \(n_{\gamma} \simeq n_v\)

\[
\frac{N_{CS}}{V(r)} = (N^W + N^Z) = \frac{\alpha_{\text{QED}}}{\sin^2 \theta_{(W)}} T^3 \left(4 \times 1.44 + \frac{2.41}{\cos^2 \theta_{(W)}}\right) = 1.2 n_{\gamma}. \tag{60}
\]

On this basis, the violation of the fermion-number density in the cosmological model being considered can be estimated as \([16]\)

\[
\frac{\Delta F^{(i)}}{V(r)} = \frac{N_{CS}}{V(r)} = 1.2 n_{\gamma}, \tag{61}
\]

where \(n_{\gamma} = 2, 402 \times T^3 / \pi^2\) is the number density of photons forming cosmic microwave background radiation.

According to Sakharov \([18]\) this violation of the fermion number is frozen by CP nonconservation, this leading to the baryon-number density

\[
n_b = X_{\text{CP}} \frac{\Delta F^{(i)}}{V(r)} \simeq X_{\text{CP}} n_{\gamma}. \tag{62}
\]

where the factor \(X_{\text{CP}}\) is determined by the superweak interaction of \(d\) and \(s\) quarks, which is responsible for CP violation experimentally observed in \(K\)-meson decays \([45]\) (see Fig. 2).

From the ratio of the number of baryons to the number of photons, one can deduce an estimate of the superweak-interaction coupling constant: \(X_{\text{CP}} \simeq 10^{-9}\). Thus, the evolution of the Universe, primary vector bosons, and the aforementioned superweak interaction \([45]\) (it is responsible for CP violation
and is characterized by a coupling-constant value of $X_{CP} \sim 10^{-9}$) lead to baryon-antibaryon asymmetry of the Universe, the respective baryon density being

$$\rho_b(\eta = \eta_L) \simeq 10^{-9} \times 10^{-34} \rho_{cr}(\eta = \eta_L). \quad (63)$$

In order to assess the further evolution of the baryon density, one can take here the W-boson lifetime for $\eta_L$.

Upon the decay of the vector bosons in question, their temperature is inherited by cosmic microwave background radiation. The subsequent evolution of matter in a stationary cold universe is an exact replica of the well-known scenario of a hot universe $[34]$, since this evolution is governed by conformally invariant mass-to-temperature ratios $m/T$.

Formulas $(47), (54), \text{ and } (63)$ make it possible to assess the ratio of the present-day values of the baryon density and the density of the scalar field, which plays the role of primordial conformal quintessence in the model being considered. We have

$$\Omega_b(\eta_0) = \frac{\rho_b(\eta_0)}{\rho_{cr}(\eta_0)} = \left[ \frac{\phi_0}{\phi_L} \right]^3 = \left[ \frac{\phi_0}{\phi_I} \right]^3 \left[ \frac{\phi_I}{\phi_L} \right]^3, \quad (64)$$

where we have considered that the baryon density increases in proportion to the mass and that the density of the primordial quintessence decreases in inverse proportion to the mass squared. We recall that the ratio $[\phi_0/\phi_I]^3$ is approximately equal to $10^{43}$ and that the ratio $[\phi_I/\phi_L]^3$ is determined by the boson lifetime in $(48)$ and by the equation of state $\varphi(\eta) \sim \sqrt{\eta}$. On this basis, we can estimate $\Omega_b(\eta_0)$ at

$$\Omega_b(\eta_0) = \left[ \frac{\phi_0}{\phi_L} \right]^3 10^{-43} \sim 10^{43} \left[ \frac{\eta_I}{\eta_L} \right]^{3/2} 10^{-43} \sim \left[ \frac{\alpha_{QED}}{\sin^2 \theta(W)} \right] \sim 0.03, \quad (65)$$

which is compatible with observational data $[20]$.

Thus, the general theory of relativity and the Standard Model, which are supplemented with a free scalar field in a specific reference frame with the initial data $\phi_I = 10^4 \ H_I = 2.7 \ K$, do not contradict the following scenario of...
the evolution of the Universe within conformal cosmology [16]:

- $\eta \sim 10^{-12}$ s, creation of vector bosons from a “vacuum”;
- $10^{-12} < \eta < 10^{-11} \div 10^{-10}$ s, formation of baryon-antibaryon asymmetry;
- $\eta \sim 10^{-10}$ s, decay of vector bosons;
- $10^{-10} < \eta < 10^{11}$ s, primordial chemical evolution of matter;
- $\eta \sim 10^{11}$ s, recombination or separation of cosmic microwave background radiation;
- $\eta \sim 10^{15}$ s, formation of galaxies;
- $\eta > 10^{17}$ s, terrestrial experiments and evolution of supernovae.

4. CONCLUSION

Within the conformal formulation of the general theory of relativity and the Standard Model, we have investigated conditions under which the origin of matter can be explained by its cosmological creation from a vacuum. We have presented some arguments in support of the statement that the number of product vector-boson pairs is sufficient for explaining the total amount of observed matter and its content, provided that the Universe is considered as a conventional physical object that is characterized by a finite volume and a finite lifetime and which is described by a conformally invariant version of the general theory of relativity and the Standard Model featuring scale-invariant equations where all masses, including the Planck mass, are replaced by the dilaton variable and where the spatial volume is replaced by a constant. In this case, the energy of the entire Universe in the field space of events is described by analogy with the description of the energy of a relativistic quantum particle in Minkowski space: one of the variables (dilaton in the case being considered) becomes an evolution parameter, while the corresponding
canonically conjugate momentum assumes the role of energy \([22, 23]\). This means that measured quantities are identified with conformal variables that are used in observational cosmology and in quantum field theory in calculating cosmological particle creation from a vacuum \([6, 7, 9, 22]\). Within the errors of observation, this identification of conformal variables with observables is compatible with data on the chemical evolution of matter and data on supernovae, provided that cosmic evolution proceeds via the regime dominated by the density of a free scalar field \(Q\) \([11, 16]\). Thus, the identification of conformal coordinates and variables used in observational cosmology and in quantum field theory with measured quantities is a first condition under which the origin of matter can be explained by its cosmological creation from a vacuum. This is possible within a conformally invariant unified theory, where the Planck mass, which is an absolute quantity in the general theory of relativity, becomes an ordinary present-day value of the dilaton and where the Planck era loses its absolute meaning.

The construction of a stable vacuum of perturbation theory by eliminating (through the choice of gauge-invariant variables) unphysical fields whose quantization leads to a negative normalization of the wave function in this reference frame is a second condition.

Finally, the elimination of divergences in summing the probabilities of product particles over their momenta by thermalizing these particles in the region where the Boltzmann H-theorem is applicable is a third condition.

Under these conditions, it has been found in the present study that, in describing the creation of vector bosons from a vacuum in terms of conformal variables, one arrives at the temperature \(\left(M_W^2 H_0\right)^{1/3} \sim 2.7\)K, of cosmic microwave background radiation as an integral of the motion of the Universe and at the baryon-antibaryon asymmetry of the Universe with the superweak-interaction coupling constant \(X_{\text{CP}} = \frac{n_\gamma}{n_\gamma}\) and the baryon density
\[ \Omega_b = \frac{\alpha_{\text{QED}}}{\sin^2 \theta(W)} \sim 0.03, \] these results being in satisfactory agreement with the corresponding observed values and being compatible with the most recent data on supernovae and nucleosynthesis.

ACKNOWLEDGMENTS

We are grateful to B.A. Arbuzov, B.M. Barbashov, A.V. Efremov, V.B. Priezzhev, and P. Flin for stimulating discussions. We are also indebted to the participants of the seminar held at the Shternberg State Astronomical Institute and dedicated to the memory of A.L. Zel’manov, especially to M.V. Sazhin and A.A. Starobinsky, for discussions on the problem of choosing the units of measurements in cosmology and on the cosmological creation of massive bosons.

REFERENCES

1. E. A. Tagirov, N. A. Chernikov, Preprint No. 2-3777, OIYaI (Joint Institute for Nuclear Research, Dubna, 1968); K. A. Bronnikov, E. A. Tagirov, Preprint No. 2-4151, OIYaI (Joint Institute for Nuclear Research, Dubna, 1968).

2. G. L. Parker, Phys. Rev. Lett. 21, 562 (1968); Phys. Rev. 183, 1057 (1969); Phys. Rev. D 3, 346 (1971).

3. A. A. Grib, S. G. Mamaev, Yad. Fiz. 10, 1276 (1969) [Sov. J. Nucl. Phys. 10, 722 (1970)].

4. R. U. Sexl, H. K. Urbantke, Phys. Rev. 179, 1247 (1969).

5. Ya. B. Zel’dovich, Pis’ma Zh. Eksp. Teor. Fiz. 12, 443 (1970) [JETP Lett. 12, 307 (1970)].

6. Ya. B. Zel’dovich, A. A. Starobinskii, Zh. Eksp. Teor. Fiz. 61, 2161 (1971) [Sov. Phys. JETP 34, 1159 (1971)].
7. A. A. Grib, S. G. Mamaev and V. M. Mostepanenko, *Quantum Effects in Strong External Fields* (Energoatomizdat, Moscow, 1988).

8. A.A. Starobinsky, Phys. Lett. B 91, 99 (1980).

9. V.N. Pervushin, V.I. Smirichinski, J. Phys. A 32, 6191 (1999).

10. L.A. Kofman, A.D. Linde and A.A. Starobinsky, Phys. Rev. Lett. 73, 3195 (1994); Phys. Rev. D 56, 3258 (1997).

11. V.N. Pervushin, D.V. Proskurin, and A. A. Gusev, Gravitation and Cosmology 8, 181 (2002).

12. H. Wentzel, *Quantum Theory of Fields* (translated from German, Ein- furung in die Quantentheorie der Wellenfelder) (Intersci., New York, 1949; OGIZ- GITTL, Moscow, 1947).

13. H.-P. Pavel, V. N. Pervushin, Int. J. Mod. Phys. A 14 2285 (1999).

14. V. I. Ogievetsky and I. V. Polubarinov, Zh. Eksp. Teor. Fiz. 41, 246 (1961)[Sov. Phys. JETP 14,246(1962)]; A. A. Slavnov, L. D. Faddeev, Teor. Mat. Fiz. 3, 18 (1970).

15. A. A. Starobinsky, Pis’ma Zh. Eksp. Teor. Fiz. 73, 415 (2001) [JETP Lett. 73, 371 (2001)].

16. D. Behnke, D.B. Blaschke, V.N. Pervushin, and D. Proskurin, Phys. Lett. B 530, 20 (2002).

17. A. G. Riess *et al.*, Astronomy J. 116, 1009 (1998); S. Perlmutter *et al.*, Astrophys. J. 517, 565 (1999); A. G. Riess *et al.*, Astrophys. J. 560, 49 (2001).

18. A. D. Sakharov, Pis’ma v Zh. Eksp. Teor. Fiz. 5, 24 (1967) [JETP Lett. 5, 17(1967)].
19. M.E. Shaposhnikov, Nucl. Phys. B287, 757 (1987); V. A. Matveev et al., Usp. Fiz. Nauk 156, 253 (1988); V. A. Rubakov and M. E. Shaposhnikov, Usp. Fiz. Nauk 166, 493(1996).

20. M. Fukugita, C.J. Hogan, and P.J.E. Peebles, ApJ 503, 518 (1998).

21. M. Pawlowski, V. V. Papoyan, V. N. Pervushin, and V. I. Smirichinski, Phys. Lett. B 444, 293 (1998).

22. M. Pawlowski and V. N. Pervushin, Int. J. Mod. Phys. 16, 1715 (2001); V. N. Pervushin and D. V. Proskurin, Gravitation and Cosmology, 7, 89 (2001).

23. B. M. Barbashov, V. N. Pervushin and D. V. Proskurin, Teor. Mat. Fiz. 132, 181 (2002).

24. R. Kallosh, L. Kofman, A. Linde and A. Van Proeyen, Class. Quant. Grav. 17, 4269 (2000).

25. D. Linde, Elementary Particle Physics and Inflationary Cosmology (Nauka, Moscow, 1990).

26. J. Schwinger, Phys. Rev. 127, 324 (1962).

27. I.V. Polubarinov, Phys. Part. Nucl. 34, 377 (2003).

28. Nguyen Suan Han, V.N. Pervushin, Mod. Phys. Lett. A2 367 (1987); V.N. Pervushin, Phys. Part. Nucl., 34, 348 (2003); L. D. Lantsman, V. N. Pervushin, Yad. Fiz. 66, 1426 (2003) [Phys. At. Nucl. 66, 1384(2003)].

29. L. Faddeev, V. Popov, Phys. Lett. B 25, 29 (1967).

30. A.M. Polyakov, Phys. Lett. B 103, 207 (1981).

31. B. M. Barbashov, N. A. Chernikov, Preprint No. P2-7852, OIYaI (Joint Institute for Nuclear Research, Dubna, 1974).
32. A. L. Zel’manov, Dokl. Akad. Nauk SSSR 227, 78 (1976); Yu.
S. Vladimirov, *Reference Frames in Gravitation Theory* (Energoizdat, 
Moscow, 1982).

33. R. Srianand, P. Petitjean, and C. Ledoux, Nature 408, 931 (2000).

34. S. Weinberg, *The First Three Minutes. A modern View of the Origin of
the Universe* (Basic Books, New-York, 1977).

35. J. A. Wheeler, *Batelle Recontres 1967*, Lectures in Mathematics and
Physics, edited by C. DeWitt and J.A.Wheeler (Benjamin, New York,
1968). B. S. DeWitt, Phys. Rev. 160, 1113 (1967).

36. C. Misner, Phys. Rev. 186, 1319 (1969).

37. S. Schweber, *An Introduction to Relativistic Quantum Field Theory*,
(Row, Peterson, Evanston, III., Elmsford, N.Y, 1961).

38. L. D. Landau and E. M. Lifshitz, *Statistical Physics* (Nauka, Moscow,
1976; Pergamon, Oxford, 1980), Part1.

39. J. Bernstein, *Kinetic theory in the expanding universe*, (Cambridge Uni-
versity Press, 1985).

40. E.W. Kolb, M.S. Turner, *The Early Universe*, (Addison-Wesley, Reading,
1993).

41. J.C. Niemeyer, Phys. Rev. D 63, 12352 (2001).

42. J. R. Bond et al. (MaxiBoom collab.), in: Proceeding of the *IAU Sym-
posium 201 (PASP)*, CITA-2000-65 (2000).

43. S. Adler, Phys. Rev. 177, 2426 (1969); J. S. Bell, R. Jackiw, Nuovo
Cimento 60 A, 47 (1969); W. A. Bardeen, Phys. Rev. 184, 1848 (1969).

44. G. ’t Hooft, Phys. Rev. Lett. 37, 8 (1976); Phys. Rev. D 14, 3432 (1976).
45. L. B. Okun, *Leptons and Quarks* (Nauka, Moscow, 1981; North-Holland, Amsterdam, 1982).