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Vacuumlike State of Matter and Inflationary Scenarios in Cosmology

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The general-relativistic dynamics of inflation is considered in its relationship to the horizon, flatness, and equation-of-state problems. There arises a doubt in the feasibility of inflationary scenarios without a violation of the energy conservation law. It is shown also that the curvature parameter is not conserved if Friedmann universe passes through a vacuumlike (false vacuum) stage. Its value later on this stage is determined by the course of the decay of a vacuumlike state into the ordinary matter. Hence no solution of the flatness problem is really offered by the known inflationary scenarios. Considering the expected properties of vacuumlike medium, the return to the idea of vacuumlike initial cosmological state seems reasonable.

I. Introduction

The impressive idea of inflation in the yearly Universe brought forward by Guth[1] not only revolutionized cosmology but also made the concept of vacuumlike medium, false vacuum, popular in the hadronic physics. This concept[2] was rediscovered by Guth in the context of application of Grand Unified Theories (GUTs) to cosmology. After the Guth's paper[1] hundreds of works have been devoted to adjusting GUTs to the inflationary scenarios and these scenarios to the current cosmological observations[3]. These works, mainly fulfilled in the framework of particle physics, have, however, paid much less attention to the general relativistic dynamics of inflation[4]. As a result, some probably misleading theoretical constructions still pretend to be a part of the general relativistic foundation of the Inflationary Cosmology.

The present work discusses these inflationary pitfalls in an attempt to lay down the general relativistic foundation for the cosmological application of the concept of vacuumlike state. It is not the goal of this paper to reveal all small inaccuracies of general relativistic treatment of inflation. Just the opposite, the present discussion is restricted by the three main problems that the Inflationary Cosmology aims to resolve. They are horizon, flatness, and equation-of-state problems. The given below simple argumentation seems to be self-sustaining enough to provide a basis for the preliminary general-relativistic analysis of the inflationary scenarios. The burdensome calculations of particular models are avoided and will appear elsewhere.

The flatness problem is related to the observational fact that the present density of the universe is very close to the critical density which corresponds to Euclidian geometry of space. To get the presently observed density in the standard Big-Bang cosmological model, one should admit that in the early universe the density was critical to the relative accuracy of 10^{-55} or more[1]. This accuracy seems to be out of any theoretical provisions.

The smoothness refers to another observational fact of the isotropy of the relic background radiation and the uniformity of the galaxy distribution in space on the scale of 10Mps and more. In essence the problem is the following. In the past, when the interactions in cosmological medium had already terminated and ceased to influence the subsequent development, the different parts of the presently observable space still were causally disconnected. Therefore the presently observable region is a mosaic of subregions which have grown independently. Why then does the isotropy and the uniformity exist on the big scale?

The inflationary cosmology extends the standard theoretical treatment of phase transitions to the physical medium of ultrahigh density. Such an extrapolation goes too far to be unquestionable. This is the equation-of-state problem.

The general conclusions of the present paper are those that the first two problems are still not resolved by the Inflationary Cosmology, whereas the attention paid to the third one is insufficient and inadequate. More, in the inflationary scenarios the energy is apparently not conserved. The quantum ingredients of inflationary scenarios can be used in improved scenarios and therefore are not devalued by these negative conclusions. These conclusions are also not to pass off the fact that the Inflationary Cosmology has rendered great services by bringing to a new life the idea of cosmological importance of the fifth aggregate state of matter - vacuumlike state.

Sec. II considers the properties of vacuumlike state. GUTs justify the very idea of vacuumlike states but so far provide almost nothing for its specific quantum description. Hence the present discussion is based on general-relativistic consideration. It seems that, for the foundation of the concept of vacuumlike state, the most important ideas are (i) participator-dependable properties of a vacuumlike medium in its macroscopic description; (ii) a self-levelling behavior of physical medium under its phase transition into vacuumlike state; (iii) the expected universal value of energy density in the vacuumlike state.

It is shown in Sec. III that a universe passing through a vacuumlike state forgets the previous value of curvature parameter. The new value of this parameter is defined by the particular way of the decay of the vacuumlike state and, in principle, can be calculated.

Sec. IV deals with the main idea of inflationary scenarios: the expansion of a small vacuumlike region to provide the isotropic matter distribution in a huge region covering all the observed part of the universe. The process of expansion, proposed by inflationary scenarios, seems to be in contradiction with the energy conservation law.

Sec. V discusses possible cosmological scenarios based on the assumption that the vacuumlike state arises as a result of a second order phase transition from a locally chaotic state into the highly symmetric state with O(4,1) de Sitter symmetry group The negative pressure is expected to be an acting internal force in a medium that is single-phase before the phase transition. Such an approach could provide new types of scenarios for the early cosmological epoch. In particular, under the decay of a vacuumlike state, considered as the initial cosmological state, the negative pressure could all over cause the formation of collapsing globules to be the first structural elements of the universe. Such an approach could be an alternative to the treatment of negative pressure in inflationary scenarios.

The concluding remarks are given in Sec. VI.

II. Vacuumlike state of physical medium

In its distinctive form the idea of a peculiar vacuumlike state of physical medium has been initially drawn[2] from the assumption that there is a parallelism between mechanical states of matter and the algebraic types of energy-impulse tensor T_{jk}. Though, unlike an ad hoc choice of Lagrangian, this idea appealed to the first principles, its applications to cosmology[2,5] was severely confined by the lack of links with quantum theories. At present this idea is justified by GUTs which, however, provide almost nothing specific about the properties of the vacuumlike state and its relation to more familiar states of matter. In particular a large freedom is left in the choice of the equation of state for a medium near its transition into vacuumlike state. Therefore, as previously, the properties of the vacuumlike state can be derived mainly from the consideration of the spacetime symmetries peculiar to the interactions between physical medium in this state and ordinary matter.

Let the energy-impulse tensor of a physical medium have the form

$$T_{jk} = -\mu g_{jk} \tag{1}$$

where g_{jk} is metric tensor and $\mu \geq 0$ the energy density. This tensor describes a degenerate, vacuumlike mechanical state. Indeed, the 4-velocity, u^i, of a continuous physical medium is the eigen-vector of the energy-impulse tensor:

$$T_{ja}u^a = -\mu g_{ja}u^a . \tag{2}$$

For matter in commonly observed states, the algebraic structure of the energy-impulse tensor guarantees the uniqueness of the 4-velocity. In this case a comoving reference frame is unique up to a space rotation. If, however, energy-impulse tensor has the form (1), any vector satisfies equation (2), i.e. for a medium in this <u>degenerate</u> state, any inertial frame of reference is a comoving frame.

To see what it means, let us imagine a freely moving test particle. The particle rest frame is automatically a comoving frame for the considered medium, so that all interactions between this medium and the particle do not depend on the particle velocity. Hence the velocity cannot be determined by the study of such interactions. In other words, for the interactions of a particle with the degenerate medium, precisely the same *principle of relativity* holds as for the interaction of a particle with vacuum. In this sense the considered physical medium is in a *vacuumlike state*. It is the state that the inflationary scenarios name "false vacuum".

The properties of the vacuum-like state that are in the direct connection with its specific spacetime symmetry can be summarized as follows:

(1) Because of the multiplicity of the comoving reference frames, one cannot introduce the concept of localization of an element of the vacuum-like medium. Consequently one cannot also introduce the concept of particles that *constitute* a vacuumlike medium.

(2) In a pure vacuumlike state the Einstein equation becomes

$$G_{jk} = \frac{8\pi G}{c^2} \mu g_{jk} \qquad (3)$$

where G_{jk} is the Einstein tensor. Because covariant derivatives of both the Einstein tensor and metric tensor vanish identically, it follows that the density of a pure vacuumlike medium does not vary either in space or in the course of time:

$$\mu = \mu_v = \text{const} . \qquad (4)$$

Hence if a non-vacuumlike medium in some region is completely converted into a vacuumlike one, the energy density of the medium during this transition must behave as *self-levelling* to become constant throughout the region.

(3)* The energy density is the only mechanical parameter that distinguishes one vacuumlike state from another. In principle, the vacuumlike states can also differ by the densities of quantum numbers. If, however, a conversion of physical medium into a vacuumlike state happens under some general *thermodynamic* conditions, the constant μ_v is expected to be *universal*. Indeed, according to equation (4) the final density in all the region covered by such a transition must be the same. Therefore the same density must appear as a result of different histories and for different initial compositions of physical substance.

(4) Formally a vacuumlike medium can be considered as the limiting

case of perfect fluid with the energy-impulse tensor of the form

$$T_{jk} = (p + \mu)u_j u_k + pg_{jk} . \tag{5}$$

where u_j is the four-velocity of the fluid, and p and μ are its pressure and density. Comparison with equation (1) shows that the fluid goes over into a vacuumlike medium at a negative pressure

$$p = -\mu . \tag{6}$$

(5)* It may seem that the negative pressure, being interpreted as a real, acting internal volumetric force, would cause an unlimited contraction of the fluid. If it was so, the concept of negative pressure would have to be rejected as a part of macroscopic theory, in particular cosmology. Under quite general conditions it is, however, not true in relativistic physics.

Substituting the equation (5) in the energy conservation law $T^{a}_{j;a} = 0$, one finds that locally

$$(p + \mu)dv/dt = -\text{grad } p \tag{7}$$

where v is the 3-velocity of the fluid and t the time. The "effective density" $\delta \equiv (p+\mu)$ plays here the role analogous to the Newtonian density in the second law of classical mechanics. Multiplying this equation by the velocity v, after simple calculations one obtains

$$d(v^2) = -(dp)/\delta . \tag{8}$$

Let at large densities the pressure becomes negative in such a way that the effective density δ goes to zero as the absolute value of negative pressure grows. Substituting in the equation (8) the expansion of pressure in a power series

$$p = \Sigma b_n \delta^n , \qquad (9)$$

one finds

$$(dp)/\delta = (b_1/\delta + 2b_2 + 3b_3\delta + ...) \qquad (10)$$

For the growth of pressure remains limited as $\delta \to 0$, one must take $b_1 = 0$. Under the descending branch, $p < 0$, $dp/d\rho < 0$, of the equation of state should be $dp < 0$, therefore $-4b_2 \equiv b^2 > 0$. This gives

$$d(v^2) = [b^2 + O(\delta)]d\delta . \qquad (11)$$

Since the velocity of a vacuumlike medium lacks physical meaning, v must vanish as δ goes to zero. Therefore, under the phase transition into a vacuumlike state

$$v^2 = b^2\delta + O(\delta^2) . \qquad (12)$$

Thus a vacuumlike state is, so to speak, *not a through state* in a sense that an evolution of a medium beyond $\delta = 0$ is impossible because the left-hand side of equation (12) is non-negative. Therefore a vacuumlike state is expected to appear only as either a final equilibrium state or the return point of a limited mechanical collapse caused by negative pressure.

(6) In the interpretation of negative pressure two limiting cases are thinkable:

a. Single-phase state with negative pressure to be an actual internal force that contributes to the compression of the medium. Then the pure vacuumlike state can appear in the second order phase transition as a limiting state.

b. Two-phase state with one phase being in one or another sense vacuumlike. Then the local conservation law can be written in the form

$$T^{m}_{i;m} = \mu_{,i} \qquad (13)$$

where μ is the energy density of the vacuumlike component and T^{k}_{i} the energy-impulse tensor for a non-vacuumlike component of the medium. This equation together with corresponding equations of state describes the energy exchange between vacuumlike and ordinary phases.

(7) Since the vacuumlike medium is isotropic, to determine its gravitational properties one can use the Friedmann equations:

$$d^2a/dt^2 = (-k/2)a(\mu + 3p) \qquad (14)$$

$$(da/dt)^2 = ka^2\mu - Kc^2 \qquad (15)$$

where $a = a(t)$ and K are the scale and the curvature parameters respectively, and $k = 8\pi G/3c^2$. The expression $r(d^2a/dt^2)$ is equal to the mutual acceleration of two test particles which are immersed in a vacuumlike medium and separated by a distance $ra(t)$. In the Newtonian case, corresponding to the sum $(\mu + 3p)$ to be replaced by μ, the acceleration would be negative, i.e., the medium would accelerate particles one toward another. Contrary to that, in the case of a vacuumlike medium the effective gravitating density $(\mu + 3p) = -2\mu$ is negative. Hence this medium has, so to speak, anti-gravitational properties and accelerates test particles one from another. As a result, a cloud of test matter immersed in a vacuumlike medium is being put in the state of expansion.

(B) Thermodynamically the vacuumlike medium seems very peculiar also. Because interactions between a particle and the medium do not depend on particle's velocity, there is no basis for the thermal exchange in the ordinary sense. The concept of localized elements of vacuumlike medium being lacking, the concept of the internal temperature in Boltzmann sense cannot be introduced.

It is well-known, however, that even in the ordinary vacuum the accelerated particle detector registers the presence of particles. The divergence of geodesics in vacuumlike medium leads to a similar effect. This time a detector, even falling freely in a vacuumlike medium, will register the presence of particles. This can be considered as an influence of internal vacuum energy and induced by it tearing gravitational forces on the zero point quantum vacuum fluctuations. It is a local interpretation of the thermodynamic effect of a cosmological event horizon[6]. The composition of this particle's stockpile corresponds to the temperature[6]

$$T_c = \sqrt{(2h^2 G\mu/\pi k_b)} \qquad (15)$$

where k_b is the Boltzmann constant. This temperature does not depend on the detector's velocity, so that the detector cannot be used to establish in a vacuumlike medium a privileged reference frame. Equally, the notion of particle in the considered phenomenon is *detector-dependent* as opposed to particles composing the ordinary matter. It cannot be said that two detectors, moving one relative to another, interact with the same system of particles. In other words, the registered particles are created as ordinary particles only in interactions between a detector and a vacuumlike medium. This shows that the interactions of ordinary matter with a vacuumlike medium are interactions with the Lorentz invariant set of zero-point quantum vacuum fluctuations.

(9) Let us touch now a delicate point of the thermodynamics of vacuumlike state.

According to the first law of thermodynamics, to change by δV the volume, V, of a body, being in equilibrium with a surrounding medium, one has to spend the energy

$$\delta Q = \delta U + p\delta V$$

where p is pressure and δU an increment of the internal energy. For a vacuumlike medium $\delta U = \mu\delta V$ and $p\delta V = -\mu\delta V$, so that

$$\delta Q = 0. \qquad (16)$$

It may seem to indicate that the work $p\delta V$ of the forces of negative pressure exactly compensates the increment $\mu\delta V$ of the internal energy. Then vacuumlike medium could be deformed, stretched or compressed without any efforts.

Such an interpretation would, however, imply the possibility of mobile perpetuum. Indeed, let in some region, filled with ordinary matter, it is occurs the phase transition into a vacuumlike state, and at the end all the available energy is invested into the arising vacuumlike medium. Let this investment be E per unit volume. It is clear that just the energy E per unit volume can be thermodynamically recovered in the reverse process. Let this region (filled now with a vacuumlike medium) grows in N times. According to the assumed interpretation of equation (16), no external energy must be involved in this process. According to equation (4), no change in the energy density of a pure vacuumlike medium is possible in space or in the course of time. (Just such expected properties of the false vacuum expansion deliver the inflationary scenarios.) Hence the reverse phase transition into a non-vacuumlike state still provides the energy release E per unit volume. Then the total energy release at the end of the reverse transition is N times more than the bulk energy in the initial state of the system though no energy is supposed to come from the outside.

This consideration, bringing mobile perpetuum, disregards, however, the fact that the idea of movement has no immediate sense in application to a medium not possessing the unique comoving frame. The notion of movement for such a medium can be defined only through the movement of ordinary matter providing boundary conditions or any other sort of merging the matter and vacuumlike medium. From this point of view, equation (16) describes only the movement of ordinary matter and only shows that this matter (e.g., the ram of an engine cylinder) moves in a vacuumlike medium without any resistance (at least in the absence of effects that are not taken into account in equation (16), such as phase transition or gravity).

The consistent consideration of the confinement of a vacuumlike medium is possible only in the framework of GR. Inside an isotropic vacuumlike medium the de Sitter metric occurs. This metric cannot be matched with Minkowski metric without a non-vacuumlike layer between.

Therefore, if a vacuumlike region is confined, its boundaries must include ordinary matter which influence on the spacetime metric is *essential*. In other words, *gravity cannot be neglected*. The movement of these boundaries is determined by the Einstein equations with corresponding matching conditions[7].

In the case of spherical symmetry, the processes outside a vacuumlike region do not influence the metric inside the current boundary of the region. Since the de Sitter metric is static, not only density but also the geometry inside an original region remains unchanged during a possible subsequent expansion of the boundaries of a vacuumlike state. Hence this expansion can proceed only due to gravitational forces and/or the phase transition of surrounding matter into the vacuumlike state.

As an example, let us consider a vacuumlike sphere. If there is no phase transition, there is in view no power stimulus for a vacuumlike sphere to expand. Indeed, according to Birkhoff's theorem, the matter outside this sphere falls on sphere's boundary as if inside the sphere would be ordinary matter. The test matter inside the sphere falls on this boundary from within but after the intersection of the boundary is gravitationally attracted to the sphere again. It is unlikely some gravitational effects, e.g., event horizon formation, can deliver energy nesessary for the vacuumlike sphere grows many times in size. The movement of thin spherical shells is now under intensive studies[7].

(10) Being isotropic and homogeneous, a vacuumlike state is incapable to transmit any information. Therefore, if the universe passed through a pure vacuumlike state, its contemporary state is independent of what was before the vacuumlike state had occurred.

The most points above formulate properties that are the direct consequences of the spacetime symmetries inherent in vacuumlike medium. Only these properties will be used below for the estimation of inflationary scenarios. The points including some assumptions are marked by the asterisk.

III. Flatness

For easier comparison of Friedmann universes possessing different values of curvature parameter K, let us assume that the co-ordinate radius r in the Robertson-Walker metric

$$c^2ds^2 = c^2dt^2 - a^2(t)\left[\frac{dr^2}{1 - Kr^2} + r^2 d\Omega^2\right] \qquad (17)$$

is measured by some standard units *common for all the universes*. Then the curvature parameter K can take any positive or negative constant value and provides a quantitative specifications of a given universe. The scale parameter a(t) satisfies the Friedmann equations (14)-(15).

To consider the flatness problem, put the state equation for the cosmological medium into the form

$$\mu + 3p = -\beta\mu \qquad (18)$$

with β to be a constant. Let us distinguish three basic states corresponding to pressure $p = (1/3)\mu$, ($\beta = -2$); $p = -\mu$, ("inflation", $\beta = 2$); and $p = 0$, ($\beta = -1$). Consider an epoch characterized by a fixed value of β. By virtue of the Friedmann equations, the ratio considered by Guth[1] becomes

$$\tau \equiv \frac{\mu - \mu_c}{\mu} = \frac{3Kc^4}{8\pi G} \cdot \frac{1}{\mu_1 a_1^2} \cdot \left(\frac{a_1}{a}\right)^{\beta} \qquad (19)$$

where μ_1 and a_1 are energy density and scale factor at some moment during this epoch, and $\mu_c = \mu_c(t)$ the critical density of cosmological medium defined by equation (19) with K=0. If an inflation phase with $p = -\mu$ is absent, one finds that near singularity

$$\tau = \frac{a^2}{a_o a_b} \tau_o \qquad (20)$$

where a is the scale factor near singularity, a_o and τ_o are the scale factor and the ratio τ at the present epoch, and a_b is the scale factor at the transition epoch when the state equation $p = \mu/3$ turned into $p = 0$ (for simplicity the duration of this epoch is neglected). According to Guth[1], at an early epoch, when one may, however, assume that unknown quantum gravitational effects have become negligible, the ratio τ is still extremely small. This is interpreted in the sense that at the early cosmological epoch the improbably fine fitting of density μ would be necessary to provide its contemporary small value $\mu=\mu_o$, corresponding to an almost flat space. It is the "flatness problem".

Flatness scarcely means more than the observed proximity of the curvature parameter K to zero, the precisely zero value being not excluded. By virtue of Friedmann equations, in general case the curvature parameter K is the integral of cosmological expansion. Let us suppose at first that it is so in inflationary scenarios also, and that between the epochs with $p = \mu/3$ and $p = 0$ there is the inflationary epoch with $p = -\mu$. Then it is easy to show that, in comparison with the contemporary value, the ratio τ increases near the singularity by a factor $(a_b/a_a)^4$, where a_a is the value of the scale factor at the starting point of the inflationary epoch. In principle, the value of this factor could be chosen so large that the ratio τ be not extremely large up to the quantum epoch when all is in a fog. This was supposed to be the solution of the flatness problem. One, however, finds that at the start of the inflationary epoch

$$\tau = \frac{a_b^2}{a_a^2 a_0} \quad . \tag{21}$$

This value is unnaturally large again, so that the extremely fine fitting near singularity is again necessary "to hit the mark over the hill". This shows that by itself the long period of the growth of the scale factor a(t) can hardly satisfactory resolve the flatness problem.

More, the consideration above leads us really on. The following statements are true: if and only if the energy-impulse tensor of cosmological medium is of the form (1): (a) the acceleration parameter a(t) of the Robertson-Walker metric (17) depends on time t exponentially; (b) independently of the value of the curvature parameter K, the metric (17) can be transformed into the form of the standard static de Sitter metric which depends on the energy density μ *only*; (c) the relative run of geodesics, i.e. the spacetime geometry, does not vary in spacetime.

It is evident from the statement (b) that if the cosmological medium somehow falls into a vacuumlike state, the subsequent development of Friedmann universe (due to, e.g., the decay of the vacuumlike medium) does not depend on the value of curvature parameter K before the vacuumlike state have arised.

All inflationary scenarios imply an enormous expansion (e.g., in 10^{65} times) after the phase transition into a vacuumlike state. Even if the admixture of ordinary matter is supposed to survive the phase transition, the density of ordinary matter is (quite reasonably) assumed falling so fast during the expansion that its influence on the spacetime metric can be neglected. Therefore inflationary scenarios just approach the conditions of dropping the value of curvature parameter off.

Let us consider the situation in less formal terms. One expects that the density of ordinary matter during the inflationary expansion becomes negligible in comparison with the invariable density of a vacuumlike medium. Thefore the frame comoving with the ordinary matter loses its physical ground. Since vacuumlike medium does not possess a unique comoving reference frame, the inflation eliminates the memory of the pre-inflation expansion, in particular of the value of the curvature parameter.

It is also unlikely that the very small residual density of ordinary matter can influence the mechanism of the back transition of the vacuumlike medium into ordinary matter. This convinces us that the value of curvature parameter, arising in the back-transition into ordinary matter, is independent of the way the vacuumlike state has appeared. In other words this value is defined by the quantum process of the decay of vacuumlike medium in its own strong gravitational field.

The cosmological issue is therefore the following: what is the frame comoving to the ordinary matter that *arises during the back transition?*

If the creation of individual particles from vacuumlike medium is going on independently of the concentration of already created particles, it is natural to expect no correlation between the peculiar velocities of created particles. Then there is no common velocity pattern corresponding to a collective motion, e.g., contraction or expansion, and one can put $\dot{a} = 0$ as an initial condition for Friedmann equation (15). Then one finds that $K>0$, i.e. the universe is closed[5].

If already created particles somehow influence the following decay of the vacuumlike medium, the conclusion concerning the type of Friedmann model cannot be so straightforward. But in any case, as distinct from the particle creation in the cosmological singularity, the process of the formation of the curvature parameter is, in principle, describable and can be calculated if the mechanism of particle creation is known (the problem will be considered elsewhere). The main point is therefore the following. *If the universe passed through the vacuumlike state , the curvature parameter observed at the present epoch was formed during the decay of this vacuumlike state.*

The appearance of exactly flat space would be difficult to explain because the expansion of the created matter arises as a secondary effect produced by a deviation of geodesics in the decaying vacuumlike medium. There is known yet no feedback action for the local process of particle creation to provide an exact final flat balance at a large space scale.

As above discussion shows, inflationary scenarios offer no ground for the universe to be flat. (Guth[1], e.g., simply speaks "I neglect k in metric, ..." avoiding any profound discussion).

The idea that inflation can provide flatness is apparently based on the assumption that the last term in the right-hand side of Friedmann equation (15) becomes negligible as a result of both the exponential growth of the scale factor a(t) and a constant value of the energy density μ during the inflation. The discussion above, however, deprives this argument of physical meaning.

IV. The horizon (smoothness) problem

The horizon (or smoothness) problem arises due to the controversy in the standard cosmological model: the early universe is supposed to be highly isotropic (and therefore homogeneous) and at the same time causally disconnected, so that no past history can be assumed that provides the global homogeneity and isotropy.

The solution, offered by the inflationary scenario, supposes that, as a result of a phase transition in the early universe, a vacuumlike phase becomes dominating in a small *causally connected* space region. Since the density of a vacuumlike medium does not vary in the absence of ordinary matter, the scale factor a(t) becomes the only variable in the Friedmann equations (14) - (15). According to them it grows exponentially until the decay of the vacuumlike state violates its monopoly on changes. No severe theoretical limitations is known on the life-time of the vacuumlike state. So, it can be chosen to fit the needs of cosmological scenarios.

The exponential growth of the scale factor inside the chosen region is interpreted by inflationary scenarios as *the growth of this region itself*, the growth that turns it into a huge isotropic (and therefore homogeneous) region which is expected to include all past of the observed part of the universe. This idea (so far disputed only by Dymnikova[4]) was expressed by Guth[1] as follows: "I am talking about a length scale L which is of course less than the horizon distance. It will then be possible to describe this local region of the universe by a Robertson-Walker metric, which will be accurate at distance scales small compared to L. When the temperature of such a region falls below <a critical value>, the inflationary scenario will take place. The end result will be a huge region of space which is homogeneous and isotropic, and of nearly critical mass density. If <the increase in linear size> is sufficiently large, this region can be bigger than (or much bigger than) our observed region of the universe."

Thus the inflationary scenarios deal with a spatially bounded region which is supposed to be exponentially expanding due to the "antigravitational" properties of the vacuumlike medium inside it. It is expected that a scenario of such a type makes it possible to solve not only both the flatness and the horizon problems but also a lot of specific problems such as monopole creation in the early universe.

Two points deliver the reasons for criticism.

First, as it was emphasized in Sec.II, the reference frame, comoving with an ordinary matter, describes the motion of the matter rather than the motion of a vacuumlike medium in which the matter is immersed. Hence, under the conditions assumed by inflationary scenarios, the scale factor a(t) describes only the expansion of test matter inside the considered region. From the fact of expansion of the test matter one can draw no conclusion concerning the region itself[4]. Second, as it was argued in Sec. II, the adiabatic expansion of a bounded region filled with a vacuumlike medium implies the creation of energy from nothing, i.e., mobile perpetuum.

These arguments against inflationary scenarios seem weighty. If, however, the assumptions of Sec. II are accepted, this fact does not mean that the very idea of a vacuumlike state of physical medium cannot be tried for the explanation of the observed smoothness of the universe For instance, the supposed property of the *self-adjusting* of the density of a medium under the phase-transition into a vacuumlike state (Sec. II) could be utilized for this goal. In combination with the expected uniqueness of the final vacuumlike state (Sec. II), this would make the conditions throughout a huge region be the same independently of a considered region to be or not to be causally connected by a common past.

V. Equation of state at high energy density

In inflationary scenarios a vacuumlike state (false vacuum) is considered to be a separate phase interacting very weakly (if at all) with another phase composed by particles. The appearance of the vacuumlike phase is commonly considered as a temperature dependent phase transition. The back-transition of the vacuumlike state into ordinary matter is supposed to arise due to a deep cooling of cosmic medium in the course of the exponential cosmological expansion reaching 10^{65} times or more.

The treatment of phase transitions by inflationary scenarios is in formal accordance with the standard theory describing such phenomena as superfluidity or superconductivity. The thermodynamic peculiarities of vacuumlike state shows, however, that the standard theory cannot be applied to this state beyond all questions.

Since a vacuumlike component of cosmic medium is strongly dominated at the beginning of the back-transition, inflationary scenarios assume that it is a vacuumlike medium itself that undergoes a deep cooling. But, as it was argued in Sec.II, the notion of temperature of a vacuumlike medium is far from to be trivial. Hence questions arise: What kind of temperature is ascribed to vacuumlike medium in these scenarios? Why does a vacuumlike medium cool down under the expansion of ordinary matter? Does the deviation from equilibrium Hawking temperature (that is high if energy density is high) play any role in the back-transition?

Another confusion that can arise is due to the standard theory deals with the diluted distributions of quantum excitons whereas the density of particles in superdense cosmological substance can be very large. This means that the ordinary modes of interactions between baryons, such as by means of mesons , could be suppressed and therefore usual mechanisms which oppose the merging of particles be annulled. Just this effect could provide a real mechanism for negative pressure to appear and cause restricted local collapse. The medium in this case would be probably single-phase.

The only clear aspect of the transition of matter into a vacuumlike state is the change in symmetry group for spacetime metric associated with the current state of matter. Locally asymmetric (or belonging to O(4) in average) before the phase transition, the metric becomes invariant under the O(4,1) symmetry group in a vacuumlike state. Therefore the weakest assumption, that can be made, is that the phase transition into a vacuumlike state is a second order one in a single-phase medium.

Thus the problem of equation of state has many aspects that remain out of vision of inflationary scenarios. Let us illustrate a possible alternative to the approach offered by inflationary scenarios. Let the phase transitions into a vacuumlike state (i) be going on in thermodynamically homogeneous single-phase medium and (ii) be governed by density as a leading thermodynamic parameter instead of temperature. Then the simplest approximation of the equation of ultradense state will be $p = p(\mu)$ with the pressure p considered a *real acting internal volumetric force* in cosmological medium[3,5]. This approach corresponds to the treatment of the vacuumlike state in Sec.II, (5).

Let us make a few remarks concerning a *contracting* Friedmann universe. The approach in consideration suggests that at a stage of ultrahigh density the pressure in a contracting universe changes its sign. The arising negative pressure must result in the *local mechanical collapse* of the medium. If the characteristic time for this collapse is less than the remaining time of the cosmological collapse of the universe, the medium splits into separate collapsing globules. This globular phase (*G-phase* in short) terminates in the end when, in the course of continuing cosmological contraction, separated globules merge to give a continuous vacuumlike medium. Such an end of the contracting universe is a *natural end* in the sense that the final vacuumlike cosmological state is not a through state for information of any kind (Sec.II, 10).

For the same reason the vacuumlike state can be considered a natural original state of an expanding universe, original in the sense that this state contains no particular information which could make vacuumlike states differ from one another. Therefore a vacuumlike state possesses *no definite past*.

Possessing no definite past, the vacuumlike state can change only stochastically. A peculiar stimulus for an outcome of a universe from a vacuumlike state does exist. Under stochastic initial conditions for the relative velocities of created particles, a vacuumlike medium gives to the spontaneously created non-vacuumlike matter an impulse for expansion. Due to this stimulus for the dissipation of ordinary matter, the local density drops and, in accordance with the equation of state $p = p(\mu)$, shifts the equilibrium from the pure vacuumlike state to that of a lesser density with an admixture of ordinary matter. This admixed matter, in its turn, is being put in expansion so that the local density continues dropping. The expansion becomes irreversible.

In principle, the evolution of this expending cosmological substratum can be drastically different from those corresponding to standard and inflationary scenarios because the expansion can include the G-phase, i.e. the decay of continuous medium into separated globules as a result of negative pressure. A cosmological globule itself evidently does not expand in cosmological sense, so that at the G-phase the general cosmological expansion becomes the expansion of the gas of globules. Mechanical and possibly gravitational collapses should be the typical way of the development of globules. The result of such a development of a massive globule can, e.g., be a galaxy formation. Then galaxies appear as the output of the G-phase rather than a consequence of gravitational instability of continuous cosmological medium.

Thus the considered equation of state could provide new types of cosmological development.

VI. Discussion

1. The necessity of general-relativistic foundation of inflationary scenarios has been underestimated. It is possible that these scenarios

are based on naive ideas that cannot find a sound confirmation in GR.

2. The very idea of a vacuumlike medium is, however, in agreement with GR and can be useful in many cosmological problems, including not only those that have provoked inflationary scenarios but also the problem of cosmological singularity. Therefore both the quantum and gravitational formulations of the properties of vacuumlike state are of extreme importance.

3. The main general-relativistic problems of cosmological vacuumlike state are apparently as follows:

The surroundings problem: the problem of relation between expanding region and its surroundings. The importance of this problem is evident from the very history of inflationary scenarios which overlooked the possibility of energy non-conservation under adiabatic expansion of bounded vacuumlike region. This problem is no less important for scenarios based on the idea of spatially restricted fluctuation in vacuumlike medium.

The topology problem: the problem of relations between a separate universe and "*the whole of creation*". Let us illustrate it by a particular example of the initial cosmological state to be the unbounded vacuumlike medium of the Planck density. Let a universe arise inside this medium as a result of a fluctuation that creates a particle-like component which begins expanding. If one assumes the Planck length to be physically indivisible, it is natural to suppose that the fluctuation occupies only the interior of an event horizon, i.e., strongly restricted. Does the expanding universe remain in touch with the vacuumlike medium (which then is its surroundings in a sense) or set apart to become an isolated world with no geodesics going into maternal de Sitter spacetime?

4. There is something paradoxical about the very idea of

inflationary scenarios. The early epoch of the universe is depicted to be a phenomenon that proceeds from a mysterious state of singularity *only* to reach another rather mysterious state, vacuumlike state, which erases all (or almost all) the information about this previous phenomenon. Though it is widely assumed that the inflationary scenarios offer an *elegant* solution of a lot of cosmological problems, a feeling arises that this gross oblivion of the dramatic creation of the universe from a singularity somehow violates *the aesthetic criterion*. *What is the singularity for?*

The dismissal of the initial singularity from cosmology would eliminate not only the faults of inflationary scenarios but also the necessity in these scenarios themselves. Maybe it is about time to return to the idea of a vacuumlike initial cosmological state?

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