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NONSINGULAR REGENERATING INFLATIONARY UNIVERSE

A.D. Linde

University of Cambridge, DAMTP, Silver St.,

Cambridge CB3 9EW, England*)

Abstract

A new version of the inflationary universe scenario is suggested which provides a possible solution of the cosmological singularity problem

*) Permanent address: Lebedev Physical Institute, Moscow 7924, Leninsky prospect 53, USSR.

There is a large interest now in the inflationary universe scenario (1 - 12), which may provide us with a solution of many cosmological problems such as the horizon, flatness and primordial monopole problems (1), homogeneity, isotropy and domain wall problems (2), and the problem of the origin of fluctuations which are necessary for the galaxy formation , 6, 12 A lot of work is to be done before any final version of this scenario will be elaborated, but the results obtained up to now (1 - 12) seem rather encouraging. However, so far it has not been quite clear whether the inflationary universe scenario, which may help us to solve so many cosmological problems, can help us also to solve the most important ccsmological problem, the problem of the cosmological singularity. It is the aim of the present paper to suggest a possible solution of this problem in the context of the inflationary universe scenario.

In order to make things as simple as possible let us first recall some features of the inflationary universe scenario. In the first version of this scenario (1) it was assumed that the phase transition from the metastable supercooled vacuum state $\varphi = 0$ to the true vacuum state $\varphi = \varphi_0$ proceeds by formation and expansion of bubbles of the field φ inside the metastable phase $\varphi = 0$. It was assumed that the field φ inside the bubble almost instantaneously grows up to its equilibrium value $\varphi = \varphi_0$, and the velocity of the bubble walls rapidly approaches the velocity of light $C = 1$. Thermalization in this scenario could occur only due to bubble wall collisions. However, Guth and Weinberg have shown (13) that the probability of the collision of the bubble formed at some time t with the bubbles created earlier asymptotically (at large t) approaches the t-independent value $N = \frac{80\pi\varepsilon}{9}$, where $\varepsilon = \frac{\lambda}{H^4}$, λ is the bubble formation probability per unit time per unit physical volume, H is the Hubble constant. Therefore if the rate of the bubble production is sufficiently small, $\varepsilon \ll \frac{9}{80\pi}$, the newly formed bubbles never collide with the bubbles formed earlier, and the phase transition never completes (non-percolation of bubbles (13)). We come to a very unusual and interesting picture of the boiling and self-reproducing (regenerating) exponentially expanding universe. Unfortunately, however, such a universe is not the best place to live in, since thermalization in this universe does not occur, and both inside and outside the bubbles there is no matter at all (13)

In the simplest versions of the new inflationary universe scenario (2, 4, 10) the phase transition also proceeds by formation of bubbles of the field φ. However in this scenario the field φ inside the bubble at the moment of its formation is much smaller that φ_o. After the bubble formation the radius of the bubble exponentially increases, whereas the field φ grows very slowly. Therefore one bubble covers all the observable part of the universe before the field φ inside the bubble grows up to $\varphi \sim \varphi_o$. Thermalization in this scenario occurs not due to the bubble wall collisions, but due to the creation of particles by the almost homogeneous field φ convergently oscillating near its equilibrium value $\varphi \sim \varphi_o$ (2, 4, 7). Let us note, however, that the bubble wall velocity in this scenario (not to be confused with the rate of growth of the bubble radius) is <u>smaller</u> than that in the old inflationary universe scenario, and approaches the veloci of light only after the field φ inside the bubble becomes sufficiently large. Therefore in the new inflationary universe scenario it is even more difficult for the bubbles to collide than in the old scenario, and from the results of ref. (13) it follows that at least for $\varepsilon \ll \frac{9}{80\pi}$ the phase transition is never completed in the whole universe. However, in the new inflationary universe scenario this fact is not dangerous at all, since thermalization occurs in each bubble separately*), and each bubble can be considered as a mini-universe which has no possibility of any causal contact (e.g. by collision) with other mini-universes.

This statement will become more precise if we call the „bubble" the region of space-time which can be somewhat affected by the formation of the bubble of the field φ. The boundary of this region moves with velocity exactly equal to that of the speed of light. Such a region has a size slightly greater than the size of the bubble of the field φ. With this new definition of the „bubble" all analysis of the bubble collisions performed by Guth and Weinberg (13) remains unaltered. This means that for $\varepsilon \ll \frac{9}{80\pi}$ most of the physical volume of the universe will never know about the existence of any bubbles, and therefore the universe as a whole (and, in particular, the space between non-percolating bubbles) will remain exponentially expanding as if there were no bubbles at all (13).

Now we come to the most important part of our paper. Usually it is assumed that the universe initially was hot and singular, and only after some cooling of the universe could start the phase transition discussed above. However in the new inflationary universe scenario this assumption is not obligatory at all. As we have seen already, if the rate of the bubble formation is sufficiently small, the phase transition is never completed in the whole universe, and at $t \to \infty$ we have an exponentially expanding boiling self-reproducing universe, which is cold (has some small constant Hawking temperature $T = \frac{H}{2\pi}$) everywhere outside some small fraction of the physical volume of the universe

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*) The possibility of such a realization of the new inflationary universe scenario with singularity at the initial stage of the universe evolution and with the regenerative regime at the inflation stage was first noticed in (8).

occupied by the bubbles. But since the universe can live in this self-reproducing stationary state forever, we may relax now our usual assumption that the universe initially was hot, and assume that the universe as a whole always was in this regenerating state. This assumption, which is in complete agreement with our previous analysis, means that our universe as a whole never was singular (e.g. the curvature scalar $R = 12H^2$ = const everywhere outside the bubbles, and is even smaller inside the bubbles). There was no beginning and there will be no end to the universe's evolution. However each mini-universe (each bubble) has its beginning in time (the time at which this bubble was formed without any coming through singularity), and its evolution after thermalization can be described by the usual hot universe theory.

Thus we see that the new inflationary universe scenario may provide us with a solution of the cosmological singularity problem.

Several comments are in order

The resolution of the singularity problem in the context of the scenario, in which many mini-universes are created from the metastable vacuum state, resembles some attempts to solve the singularity problem by assuming creation of the universe from „nothing" (14) or from some other universe (15). However in distinction to our scenario, in the latter approaches to the singularity problem it is assumed that there was some moment before which our physical space and time have not existed. From our point of view such a resolution of the singularity problem would be somewhat incomplete, since the most important part of this problem is just a question of how it could be that sometimes(?) our space and time have not existed. Of course, one could argue that near the cosmological singularity our usual concepts of space and time do not work, and the resolution of the singularity problem might be found after the proper development of the quantum gravity theory. It seems to us, however, that it would be not too bad to have a possible solution of the singularity problem which would not require any crucial changes of the usual concepts of space and time in the very early universe

2 It is sometimes assumed that there might be many different universes, and we live in just one of them, which is sufficiently suitable for the existence of life and human consciousness. This assumption is one of the possible motivations of the Anthropic Principle in cosmology (for a recent discussion of some relevant issues see e.g. 16, 17)). However, it was not quite clear whether God actually could play the game of the universe creation many times before the final success (?), or maybe one could try to make some sense out of this many-universe hypothesis e.g. in the context of quantum gravity. It may be of some interest therefore that in the scenario suggested above the universe contains an infinite number of mini-universes (bubbles) of different sizes, and in each of these universes the masses of partic coupling constants etc. may be different due to the possibility of different symmetry breaking patterns inside different bubbles. This may give us a possible basis for some kind of Weak Anthropic Principle: There is an infinite number of causally unconnected mini-universes inside our universe, and life exists only in sufficiently suitable ones.

3. The nonsingular regenerating inflationary universe scenario suggested above can actually be realized only in theories in which bubble formation is sufficiently strongly suppressed (small ε). On the other hand, in order to have a large inflation the curvature of the effective potential $V(\varphi)$ near $\varphi = 0$ should not be too large (2-4, 6, 10). Presumably both these conditions can be satisfied in a theory with a small positive mass squared of the field φ, $m^2(\varphi = 0) \ll H^2$, and with a sufficiently small scalar coupling constant λ (2, 6, 10).

It is worth noting that the nonsingular inflationary universe scenario can be implemented not only in the context of grand unified theories, in the context of quantum gravity as well. For example, a sufficiently large inflation of the universe can be achieved in the Starobinsky model 18) However, according to this model the universe initially was in the unstable vacuum state. The lifetime of the universe in such a vacuum state is finite (11) (as distinct from the lifetime of the universe in the regenerative state considered in the present paper). This means that such a vacuum state could not exist at $t \to -\infty$*), and therefore for realization of the Starobinsky scenario it is necessary for the universe to be created in the unstable vacuum state either from „nothing" (14) or from some other universe (15). Recently a modification of this model was suggested, in which the vacuum state initially was metastable rather than unstable (20). theory of the vacuum decay in this model almost coincides with that in the inflationary universe scenario. One may expect therefore that the nonsingular regenerating inflationary universe scenario can be implemented also in the context of the modified Starobinsky model mentioned above

We see therefore that there exist several different versions of the new inflationary universe scenario, which may help us to solve not only the horizon, flatness, homogeneity and isotropy problems, but also the cosmological singularity problem. Of course, our present understanding of the phase transitions in the exponentially expanding universe is still far from being complete, and a more detailed analysis of this question

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*) A similar comment can be applied also to a recent paper by Atkats and Pagels (19), in which it is assumed that the lifetime of the universe in the initially nonsingular state is finite.

is needed in order to verify whether the nonsingular inflationary universe scenario can be implemented in the context of realistic theories of elementary particles. In any case, however, the very possibility of obtaining a solution to all the most important cosmological problems in the context of a unique rather simple scenario seems very interesting and clearly deserves further investigation.

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