Rep. Prog. Phys., Vol 47, pp 925–986, 1984. Printed in Great Britain

The inflationary universe

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Abstract

According to the inflationary universe scenario the universe in the very early stages of its evolution was exponentially expanding in the unstable vacuum-like state. At the end of the exponential expansion (inflation) the energy of the unstable vacuum (of a classical scalar field) transforms into the energy of hot dense matter, and the subsequent evolution of the universe is described by the usual hot universe theory.

Recently it was realised that the exponential expansion during the very early stages of evolution of the universe naturally occurs in a wide class of realistic theories of elementary particles. The inflationary universe scenario makes it possible to obtain a simple solution to many longstanding cosmological problems and leads to a crucial modification of the standard point of view of the large-scale structure of the universe.

This review was received in February 1984.

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energy cancellation between the 'up' and 'down' vacua seems so simple and natural that it would be a pity to abandon such a possibility without a detailed investigation.

Another possible way of solving the cosmological constant problem is related to quantum cosmology. The vacuum energy density may depend on the topology of the compactified part of space (Sakharov 1984) and on some classical fields of the type of the antisymmetric tensor field $A_{\mu\nu\lambda}$ (Ogievetsky and Sokatchev 1980, Duff and van Nieuwenhuizen 1980, Aurelia *et al* 1980). This field, just as the scalar field φ, appears simultaneously with quantum creation of the universe (Hawking 1984a, b). However, contrary to the scalar field φ, the field strength $F_{\mu\nu\lambda\sigma}$ of the field $A_{\mu\nu\lambda}$, which gives the contribution $V(F)$ to the vacuum energy $V(\varphi, F) = V(\varphi) + V(F)$, remains constant during the subsequent classical evolution of the universe (Ogievetsky and Sokatchev 1980, Duff and van Nieuwenhuizen 1980, Aurelia *et al* 1980). As follows from equation (13.7), the universe is created most probably in a state with $V(\varphi, F) \gtrsim M_p^4$ (Linde 1984c, d, Starobinsky 1984b). However, this does not impose any constraints on the value of $V(F) = V(\varphi, F) - V(\varphi)$ since the value of $V(\varphi)$ at the initial stages of inflation can be arbitrarily large (see § 11). Therefore, *after* symmetry breaking any value of vacuum energy density $V(\varphi_0, F) = V(\varphi_0) + V(F)$ may appear with approximately the same probability. At $|V(\varphi_0, F)| \gg 10^{-29}$ g cm^{-3} life of our type would be impossible. The value $|V(\varphi_0, F)| \lesssim 10^{-29}$ g cm^{-3} *a priori* does not seem very probable. The eternally oscillating universe scenario is not of much help here, since the closed universe with $V(\varphi_0, F) > 0$ can expand forever, which would break the chain of oscillations (see § 13). What may occur, however, is a multiple quantum production of 'new' universes from the 'old' ones. Such a process looks like an infinite chain reaction, which is possible due to the gravitational instability discussed in § 13 (see also a paper by Englert and Nicolai (1983) in which similar ideas were suggested). During this process infinitely many universes can be produced, in some of which $|V(\varphi_0, F)| \lesssim 10^{-29}$ g cm^{-3} and life of our type may exist. This is a possible solution of the cosmological constant problem based on the implementation of the anthropic principle in quantum cosmology.

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