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ORIGINAL ARTICLE

FRW models with particle creation in Brans-Dicke theory

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Abstract The thermodynamical effect of particle creation on the early evolution of Friedmann-Robertson-Walker universe is analyzed in the context of open thermodynamical systems within the framework of Brans-Dicke theory. The field equations are solved exactly using the "gamma-law" equation of state $p = (\gamma - 1)\rho$, where the adiabatic parameter γ depends on the scale factor of the universe. We assume the functional form of γ in such a way that it describes a unified description of two early phases of the evolution of the universe, viz. *inflationary phase* and *radiation-dominated phase*. The role of Brans-Dicke scalar and creation of matter particles is investigated during the expansion of the universe. It is found that the expansion of the universe is driven by the particle creation in each phase. The physical and geometrical behaviors of the solutions are discussed in detail.

Keywords FRW model · Brans-Dicke theory · Power-law expansion · Particle creation

1 Introduction

In Einstein's general relativity, the gravitational constant G, velocity of light c and cosmological constant Λ are all proper constants. A conceptually simple way to extend Einstein's theory of general relativity is to suppose that the gravitational term G is time dependent. The concept of a time—dependent gravitational constant G was first introduced by Dirac (1937, 1938) based on the large number hypothesis (LNH). A time-dependent G then follows as a natural consequence of the LNH. In the past there were some interesting attempts to generalize the general theory of relativity with variable G. One of the important modifications were proposed by Brans and Dicke (1961), known as Brans-Dicke (BD) scalar-tensor theory of gravitation. In this gravitational theory, in addition to the space time metric, a scalar field ϕ is introduced as a dynamical variable. The scalar field ϕ has the dimension of inverse of the gravitational constant and its role is confined to its effects on gravitational field equations. The introduction of the scalar field in this theory makes it more consistent with Mach's principle since Mach's principle is not substantiated by general relativity. In BD theory, a dimensionless free coupling parameter ω is introduced between the scalar and tensor components of gravitation. From observational point of view, the BD theory is consistent for $\omega \geq 500$ (Will 1981). However, there is no restriction on the value of ω from a cosmological stand point, and BD theory goes over to general relativity at the limit of $\omega \to \infty$, $\phi = const. = G^{-1}$. A detailed survey of the Brans-Dicke (BD) theory have been done by Singh and Rai (1983).

It is generally accepted that BD scalar-tensor theory plays an important role in the present view of the very early universe. More recently the interest of this kind of theory was renewed, owing to its association with superstring theories, extra-dimensional theories and models with inflation or accelerated expansion. The simplest inflationary models (Dominici et al. 1983; Mathiazhagen and Johri 1984), extended inflation (La and Steinhardt 1989) and hyper extended inflation and extended chaotic inflation (Linde 1990; Steinhardt and Accetta 1990) are based on BD theory and other general scalar-tensor theories. Uehara and Kim (1982) have studied BD theory with cosmological constant Λ and presented exact solutions for spatially flat Friedmann-Robertson-Walker

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