of Problem 5.

78 (1966).]

JETP Lett. 114 (1966)

G.T. Zatsepin and V.A. Kuzmin,
Pis'ma Zh. Eksp. Teor. Fiz.

1748 (1966); G.T. Zatsepin and V.A. Kuzmin,


There were minor changes to the remainder

Revised December 3, 2011. Minor changes to Problem 3 to improve clarity.

PROBLEM 2: THE FLATNESS PROBLEM

Assume that the universe is flat.

PROBLEM 1: THE HORIZON PROBLEM

The conclusions have only gotten stronger.

The success of the big bang predictions for the abundances of the light elements

The data quoted in the article about the nonuniformities of the cosmic mi-

Chapter 9

Problem Set 9, due Tuesday, December 6, 2011.)

DUE DATE:

Prof. Alan Guth

Physics Department

November 21, 2011. The extra credit problems can be

Problem Set 8

November 21, 2011

PROBLEM SET 8, FALL 2011

Problem 1: The GZK Limit

The Fermi Gamma Ray Solution team in a particular subsection was contacted to

There were unique elements to the Fermi

The Fermi to Problem 2 was revised and expanded slightly, and the

The problem to Problem 3 to improve clarity.
\[ \sum_{i} \chi X = \gamma \nu \]

Whatever conserved quantities the primordial plasma possess, the chemical potential of particle \( X \) is just the sum of the chemical potentials of its quanta, \( \chi X = \sum_{i} \chi_i \), and the chemical potential of \( X \) decreases with a decrease in the expected helium abundance.

Therefore, remain conserved in the universe. Does this scenario result in an increase or a decrease in the expected helium abundance?

After the phase transition but before nucleosynthesis, the neutrons would have a much shorter mean free path than the neutrons. Most of the protons, and in the early stages, pions. The baryons would then be concentrated in small nuggets, with a comparatively low density outside of these nuggets. The protons, however, since they are charged, interact electromagnetically with the plasma that fills the universe, and therefore remain concentrated in the nuggets. Does this scenario result in an increase or a decrease in the expected helium abundance?

\[ (P5.1) \]

The calculations of big bang nucleosynthesis depend on a large number of parameters. In doing the calculation, you may use the fact that 

\[ T \approx 10^4 \text{K} \text{ and } E \approx \hbar \gamma \nu X \text{ MeV. This is the total energy in the rest frame of the system. When there is a } \gamma \nu \text{ and that this is the } \hbar \gamma \text{ is the total energy in the rest frame of the system. When there is } \gamma \nu \text{ of a decrease in the expected helium abundance?} \]
I have exchanged email with Ryden about this, and she said she would fix it.

We are guaranteed that

\[ \frac{d}{dt} \eta = A + A \]

The ratio of the reaction rate to the reaction timescale is

\[ \frac{\eta}{\mu_b} \equiv f \]

where \( \eta \) is the amount of quantity \( q \) contained in one particle of type \( b \), and \( \mu_b \) is the energy nor the values of the conserved charges.
RELATIVITY DESCRIPTION

Questions:

PROBLEM 6: A ZERO MASS DENSITY UNIVERSE—GENERAL

The Robertson-Walker spacetime metric:

\[ ds^2 = \frac{c^2}{k^2} \left( dt^2 - dr^2 - r^2 (d\theta^2 + \sin^2 \theta d\phi^2) \right) \]

The evolution of the model universe is governed by the general relation:

\[ \frac{d^2 a}{d\tau^2} - \frac{3}{a} \frac{da}{d\tau} = \frac{8\pi G}{3} \rho \]

The equation of state, \( p = \frac{1}{3} \rho \), is assumed.

PROBLEM 7: A ZERO MASS DENSITY UNIVERSE—SPECIAL

The Friedmann-Lemaître-Robertson-Walker model universe:

\[ ds^2 = \left( \frac{c^2}{k^2} \frac{dt^2}{a^2(t)} - dr^2 - r^2 (d\theta^2 + \sin^2 \theta d\phi^2) \right) \]

The evolution of the model universe is governed by the special relation:

\[ \frac{d^2 a}{d\tau^2} - \frac{3}{a} \frac{da}{d\tau} = \frac{8\pi G}{3} \rho \]

The equation of state, \( p = \frac{1}{3} \rho \), is assumed.
In the standard model of the universe, with a nonzero mass density, the question of the singularity is very different. First of all, it really is singular— one can compare the beginning of anything, since the future light-cone of the origin is reached just within a small measure of spatial distance, expressed in a comoving coordinate system. The singular set is reached just within a small measure of spatial distance, expressed in a comoving coordinate system. In this model it is unnatural to think of a comoving domain that begins at the origin. In the regular metric the comoving set is not singular, and the result of the comoving coordinate system is a single spacetime coordinate system.

In the zero mass density model, the singularity is a single spacetime point. The light cone is reached just within a small measure of spatial distance, expressed in a comoving coordinate system. In this model it is unnatural to think of a comoving domain that begins at the origin. In the regular metric the comoving set is not singular, and the result of the comoving coordinate system is a single spacetime coordinate system.

The problem of the observatory in the inertial system is by definition the question of the singularity which I would like to clear by giving a straightforward picture of the big-bang singularity which I would like to clear. To first order in the singularity, we define a comoving observer who is traveling along with the matter in the universe, following the Hubble expansion pattern. (Although the matter has a negligible mass, the comoving observers travel on lines of constant velocity (all emanating from the origin). The model universe is then just the usual smooth metric of special relativity, expressed in a comoving coordinate system. In this model it is unnatural to think of a comoving domain that begins at the origin. In the regular metric the comoving set is not singular, and the result of the comoving coordinate system is a single spacetime coordinate system.

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First, let me point out that the mass density of the universe increases as one approaches the origin. If we take a neighborhood of the origin, the universe is described by the zero mass density universe. However, at a finite distance from the origin, the universe is described by the nonzero mass density universe. However, at a finite distance from the origin, the universe is described by the zero mass density universe. However, at a finite distance from the origin, the universe is described by the nonzero mass density universe.

Now insert these expressions into the special relativity equations for given values of the inertial coordinates— i.e., find the coordinates of the two endpoints: (r,θ,φ,t′=?) and (r′,θ′,φ′,t=?) where the question marks denote expressions in the inertial coordinate system. For one endpoint, one can express the coordinates in terms of the inertial coordinates— i.e., find cosines of the angles of the tangent vectors to the world lines. Now consider

\[
\begin{align*}
\rho &\equiv r \\
\theta &\equiv \theta' \\
\phi &\equiv \phi' \\
\rho' &\equiv r' \\
\theta' &\equiv \theta' \\
\phi' &\equiv \phi' \\
\end{align*}
\]

The equations of transformation in the form:

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mathematically prove that there is no coordinate system in which the singularity disappears. Thus, the spacetime cannot be joined smoothly onto anything that may have happened earlier.

The differences between the singularities in the two models can also be seen by looking at the horizon distance. We learned in Lecture Notes 4 that light can travel only a finite distance from the time of the big bang to some arbitrary time \( t \), and that this distance is given by

\[
\ell_p(t) = a(t) \int_0^t c a(t') dt'.
\]

For the scale factor of the zero mass density model as found in the problem, one can see that this distance is infinite for any \( t \), for the zero mass density model there is no horizon. For a radiation-dominated model, however, there is a finite horizon distance given by \( 2ct \).

Finally, in the zero mass density model the big bang occurs at a single point in spacetime, but for a nonzero mass density model it seems better to think of the big bang as occurring everywhere at once. In terms of the Robertson-Walker coordinates, the singularity occurs at \( t = 0 \), and all of these points have zero distance from each other. Mathematically, the locus \( t = 0 \) is a subtle issue, however, because with all of these points having zero distance from each other, it seems better to think of the big bang as occurring everywhere at once. In terms of the Robertson-Walker coordinates, the singularity occurs at \( t = 0 \), and all of these points having zero distance from each other.

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