Notice should be taken of the disintegration of α particles and other nuclei [6] as they pass through metagalactic space. This occurs at an α-particle energy somewhat lower than the proton energy at which the pion photoproduction process begins. The rather large cross section of this process should lead to total disappearance of the nuclei from the cosmic rays at energies above 10^{19} eV.

Note. After writing this article, we received a preprint of a paper by K. Greisen, in which similar reasoning is presented and estimates agreeing with ours are obtained.

The authors take this opportunity to thank K. Greisen for communicating his unpublished results.

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CHARGE ASYMMETRY AND ENTROPY OF A HOT UNIVERSE

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Measurements of the cosmic background of radio emission at wavelengths 20, 7, 3, and 0.25 cm [1,2] have confirmed the theory of the hot Universe [3,4] [1]. The dimensionless entropy (per baryon, in a system of units where the Boltzmann constant is k = 1), amounts to approximately 10^9. This means that there are approximately 10^8 quanta of electromagnetic radiation per baryon, and approximately as many electrons and muonic neutrinos.

From this it follows that for the earlier period $t < 10^{-6}$ sec (reckoning from the instant of singularity, $t = 10^{-6}$, corresponds to a temperature T = 100 MeV and a density $\rho = 5 \times 10^{17}$ g/cm^3) there are likewise approximately 10^8 baryon-antibaryon pairs per baryon. Thus, asymptotically as $t \to 0$ there are $\bar{N}$ = 99,999,999 antibaryons and approximately as many mesons and leptons for each N = 100,000,000 baryons [2]. The small but conserved difference $\Delta = N - \bar{N}$ (the composition is referred to $\Delta = 1$) plays the decisive role for the entire subsequent evolution of matter!

This almost-charge-symmetrical state seems quite unnatural. The alternative hypothesis of complete charge symmetry of the Universe [2,6] does not seem convincing to us. We shall attempt below to present a natural explanation of the aforementioned small charge asymmetry at high density.

There are no grounds for excluding from consideration the period of time $t \sim 10^{-6}$ sec, when $\rho \approx 10^{17}$ g/cm^3, since the limits of applicability of general relativity theory and of relativistic cosmology correspond to $t = 10^{-43}$ sec and $\rho = 10^{93}$ g/cm^3 [7]. The period 1 sec $< t <$ 100 sec is considered quantitatively and leads to conclusions that do not contradict observations [8] concerning the composition of prestellar matter.

A rational solution of the puzzle of the almost-charge-symmetrical state can be found by assuming that a phase when matter was compressed existed at $t < 0$.

Let us assume that at $t \simeq -10^{18}$ sec there were no antibaryons at all, and that only baryons existed (nucleons, ordinary nuclei, ions, and atoms). The average density at this instant was 10^{-30} g/cm^3. Let us assume that up to that instant there was released an energy of the order of $E = 10^{16}$ erg/g as a result of nuclear reactions or gravitational processes (if we choose a later instant of time when ρ is larger, the required energy E increases, $E = 10^{28}(-t)^{\frac{2}{3}} = 10^{26}\rho^{\frac{1}{3}}$). For comparison we recall that the rest mass is 9×10^{20} erg/g, the energy of the $H \to H^4$ transformation is $\sim 7 \times 10^{18}$ erg/g, while the gravitational potential on the surface of the sun is 2×10^{15} erg/g.

During the course of contraction this energy (which initially could be in the form of optical quanta and high-energy neutrinos) should be transformed into equilibrium forms; the presented value of E ensures the necessary entropy. In this case the occurrence of baryon-antibaryon pairs and the surprising almost-charge-symmetrical state are already a natural consequence of the known laws of physics.

It is also natural to assume that the transition from contraction to expansion does not violate the known conservation laws for the baryon charge and for the specific entropy.

Consequently, during the expansion phase we have the same high specific entropy and almost complete charge symmetry at high densities. In particular, it follows from this that cyclic evolution with an infinite number of contraction and expansion cycles does not agree with the finite value of the entropy at the present time.

A general difficulty of any hypothesis in which contraction gives way to expansion (including the proposed hypothesis) is the question of the spatial homogeneity of the matter during the earlier stage. The presently observed picture calls, apparently, for a high degree of homogeneity of the initial (singular) state [9], and it is not clear whether the inhomogeneities become equalized by the light pressure and by the plasma pressure under various possible assumptions concerning the state of matter at $t < 0$, during the contraction phase.

We chose above the instant of release of the given energy in such a way as to obtain for the entropy S a value known from observations. In principle, the fundamental theory itself should lead to a definite value of S. For example, if we assume that at $t < 0$ the matter is homogeneous and consists of particles with mass of the order of the nucleon mass m, which release an energy of the order of mc^2 and become transformed into nucleons by collision, with cross section $(\hbar/mc)^2(c/v)$, then simple calculation yields

$$S^2 \cong \frac{\hbar}{mc} : \sqrt{G\hbar/c^3} = l_c : l_g = 10^{-14} \text{ cm} : 10^{-33} \text{ cm}, \quad S \sim 3 \times 10^8,$$

where ℓ_c is the Compton wavelength of the nucleon, and ℓ_g is the gravitational unit of length [7].

Thus, the quantity S, which is fundamental for cosmology, may possibly be expressed in terms of a combination of atomic and gravitational quantities. The expression for S differs from the outwardly analogous formulas of Eddington, Dirac, and others in the fact that S is a local quantity and the expression has been derived logically, from a consideration of physical processes during the course of the evolution.

Doubts are raised by concrete assumptions concerning the energy release, and especially concerning the homogeneous distribution of particles (on a microscopic scale!). We present the result only in order to emphasize that a new theoretical problem has arisen, that of calculating the large dimensionless quantity S.

The energy conservation law for the Universe as a whole [3)] does not limit the specific energy E_1 per baryon, which is measured locally. The release of the small energy $\Delta E_1 \ll mc^2$ and subsequent contraction lead to a state in which $E_1 \gg mc^2$ and, in particular, to the production of N-$\bar{N}$ pairs in an amount exceeding the initial number of baryons.

We can thus assume that the Universe is 100% charge-symmetrical, with the exception of a short high-density period, when it is almost symmetrical for natural reasons.

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1) An explanation of cosmic radiation by attributing it to release of energy in protostars with subsequent cooling of the radiation by dust is of low likelihood [5].

2) At a density $\rho > 10^{17}$ g/cm^3 the dimension of the volume per baryon is smaller than the Compton wavelength and it is not clear whether one can speak of individual baryons and antibaryons. However, at a density, say, 2×10^{17} g/cm^3 there are no doubts concerning the applicability of the concepts baryon and antibaryon, and almost complete charge symmetry already exists.

3) The energy of the closed world is identically equal to zero, that of an open world is infinite.