Equations (A.4) near the singular points F_5 and F_6 require a special investigation, which we shall not make here. We merely point out that for $\nu < \frac{1}{2}$ there exists a bundle of curves that enter the point F_6 from below and the left (from the third quadrant) and have near F_6 a common tangent, so that, taken as a whole, F_6 is in this case a complicated node–saddle type state. But if $\nu > \frac{1}{2}$, the point F_6 only repels the curves. The main bundle in this case comes out of F_6 upward and to the left (into the second quadrant), having a common tangent. The point F_5 for $\nu < \frac{1}{2}$ attracts curves from the first quadrant (upward and to the right), and for $\nu > \frac{1}{2}$ there is a bundle of curves that go out of it downward and to the right (into the fourth quadrant). In the last case, F_5 is a complicated node–saddle state.

Having elucidated the behavior of the integral curves of the system (A.4) in the physical region of the phase space ($\varphi \geqslant -\pi/4$) for every range of variation of ν, we can, using the transformations (A.2) and (A.3), then establish the picture of the integral curves in the variables (H, ε); this is shown in Figs. 2–4.

1)We use a system of units in which the velocity of light and Einstein's gravitational constant are equal to unity. The metric is described in the form $-ds^2 = g_{ik}\,dx^i\,dx^k$, where g_{ik} has the signature ($-+++$). Latin indices take the values 0, 1, 2, 3 and Greek the values 1, 2, 3 and $(t, x, y, z) = (x^0, x^1, x^2, x^3)$.

2)We shall not consider the special case $\lambda_1 = 0$ of tangency of the curves, regarding this as too special and unjustified. This case is considered in detail in[4].

3)We recall that here we do not include possible intersections or tangency of these curves for $\varepsilon = 0$.

4)In Murphy's solution,[7] which corresponds to a flat Friedmann model with viscosity of the form $\zeta = \text{const}\cdot\varepsilon$ ($\nu = 1$), the scale factor $R(t)$ is nevertheless zero at the start of expansion (as $t \to -\infty$).

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A new type of radioactive decay: gravitational annihilation of baryons

Ya. B. Zel'dovich

Institute for Applied Mathematics, USSR Academy of Sciences, Moscow

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Some considerations are presented in favor of baryon-number nonconservation at the elementary particle level if the strong gravitational interaction at short distances is taken into account. A rough and unreliable estimate is given for the decay time of nuclei according to this mechanism.

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The application of gravitation theory to elementary particles leads to the conclusion that processes are possible which would manifest themselves as the conversion of baryons into neutral particles, e.g., $2N = (\pi^+, \pi^-, \pi^0)$ with apparent nonconservation of baryon number (baryonic charge, in the original). In these processes the rest mass of the baryons is totally converted into energy. Such a process may occur spontaneously in an atomic nucleus and even with an individual nucleon, $p \to e^+ + \pi^0$. Electrically neutral system can undergo oscillations, similar to the kaons; thus, the hydrogen atom can go over into its antiatom: $H = (pe^-)' \rightleftarrows (\bar{p}e^+) = \bar{H}$. At extremely high temperature processes of the type $\nu + \nu \rightleftarrows N + N$ become possible.

Extremely rough estimates for nuclei (stable with respect to the known decay modes) yield a lifetime of the order of 10^{45} years, which does not contradict the experiments of Reines[1] and of others. There are small chances that the probability is substantially larger, but the opposite result is also possible after a consistent theory will be developed for this phenomenon. Experimental detection of the presumed decay type is extremely difficult. On the other hand, a high-temperature reaction is likely to become comparable to other processes near the cosmological singularity, when the characteristic time is of the order of the Planck time 10^{-43} s. We assume that no new fundamental lengths will appear between the experimentally studied region of lengths and times and the Planck units of length and time[2] and that no fundamental change of the laws of nature occurs there.

What is the basis of this hypothesis? It has been known for a long time that the mass of a three-dimensionally closed universe vanishes identically. The local

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law of baryon conservation allows for the disappearance of baryons from the observable region of space with a simultaneous modification of the general topology and the formation of a closed manifold not connected to the observable region. The baryons end up in the closed space and, in accordance with the law of conservation of energy, there appears in the observable space in their place a neutral (i.e., having zero baryon number) bunch of particles, e.g., mesons and photons. Formally, the proposed model is analogous to the possibility of creation of closed universes on the background of a flat empty space, as noted by Fomin.[3] Fomin's empty space (the "vacuum") does not change in the process. In our case, in the presence of matter the baryon number changes without a change in the total energy of the matter.

In classical (as opposed to quantized) Einstein gravitation theory a change in topology is related to the appearance of a singularity. It is possible that this is the reason why the possibility and probability of this process has not been discussed before (as far as the author is aware).

In recent years there has appeared a formulation of "baryon nonconservation near a black hole,"[4] since it became apparent that the mass, angular momentum and electric charge of a black hole completely determine the metric and the field for $r > r_g$. The vanishing of the massless vector meson field (whose sources may be the baryon number) outside the horizon is interpreted as the impossibility of measuring baryonic charge.

Beckenstein[4] concludes from this, even in the title of his article, that baryons are not conserved in black holes. The situation has remained unclear, since even in the absence of a gravitational field, when the vector field outside the atomic nucleus does not vanish, its magnitude (the coefficient c in the asymptotic expression $y = ce^{-\mu r}/r$) is not uniquely determined by the number of baryons, but also depends on their spatial distribution. The number of baryons could conceivably change also for a constant c. Baryon conservation in the "usual" physics in flat Minkowski space has the character of an assertion regarding the world line of the baryon.[1)]

Nevertheless the subsequent development of the theory led to a constructive confirmation of the hypothesis of nonconservation of baryon number in black holes. Until 1974 a black hole was regarded as an object which from the point of view of a remote observer freezes (for $t \to \infty$) in a definite limiting nonsingular state. Baryon number conservation seemed obvious. However, later came the remarkable theoretical discovery of evaporation of black holes.[5] The evaporation of black holes was considered as pair production on the background of a slowly varying metric. When the mass decreases to the Planck value $(\hbar c/G)^{1/2} \sim 10^{-5}$ g, this approximation is no good. One must appeal to cosmological considerations. It is unlikely that such and similar black holes are not abundantly formed near the singularity. But today there are none around us in any noticeable quantity.[6,7] This means that the evaporation does not stop at a mass of the order of the Planck mass. The last stage of evaporation can only be pictured as a quantum jump with the black hole and everything it contains disappearing from our space.

A comparison of generalized cosmological observations with Hawking's theory[5] leads to the conclusion that it is possible that a small closed universe splits off spontaneously from our universe.

Hawking's theory does not require a consideration of the state of matter situated below the horizon, and the assertion that a separate closed universe is formed exceeds the bounds of this theory. Here we essentially introduce a new hypothesis (cf.[3]) that a quantum change of the topology is possible. But Hawking's theory leads one close to this hypothesis and makes it quite likely. An additional element is given by the correspondence: a closed universe carries no electric charge—complete evaporation is possible in Hawking's theory only for an electrically neutral black hole; the baryon number of a closed universe may be arbitrary—the baryon number of a black hole does not prevent it from evaporating.

We now turn to the dynamics of baryon nonconservation. There are two limiting cases. The first is: the formation and conversion into energy of a black hole with mass larger than the Planck mass. The process occurs classically during the first stage of formation of the black hole and is a quantum process on the background of a classical metric during the evaporation process, except for the last stage. However, outside the cosmological singularity the conditions necessary for the classical formation of black holes do not exist,[6,7] except for stars with mass of the order of the solar mass, which practically do not evaporate.

A subbarrier-tunneling quantum-mechanical production of a black hole with Planck mass in compressed matter, e.g., inside a white dwarf or a neutron star is practically excluded: in the exponent of the probability of the tunneling process there appears the number $(\hbar c/Gm^2)^{3/2} = 10^{57}$, i.e., the process is small of order $\exp(-10^{57})$.

In the present paper we make an attempt to consider another case of conversion into energy of the mass of one or two elementary particles, i.e., of masses much smaller than the Planck mass (in the ratio $10^{19} = (\hbar c/Gm^2)^{1/2}$). One cannot separate individual stages in this process. The very possibility of considering such small masses and lengths causes doubts. However, the methodological difficulties of the calculation do not mean that the process is physically impossible. How should one approach an estimate of its probability? We imagine a gas consisting of point particles of rest mass m, gas density n, and having a semirelativistic velocity $\gamma - 1 \simeq 1$. We determine the number of collisions of this gas which lead to annihilation. This number is proportional to n^2. The probability of conversion of two particles into two other particles is proportional to the phase volume $E^2 \simeq m^2$. In the system of units with $\hbar = c = 1$ the number N of processes per 1 cm^3 per second has the dimension (mass)^4. We set $N = n^2 m^2 G^\alpha$ and for dimensional reasons $\alpha = 2$. Transforming into a probability $w(s^{-1})$ of one particle entering into a reaction, and in dimensional units

$$w=n\left(\frac{\hbar}{mc}\right)^3\frac{mc^2}{\hbar}\left(\frac{Gm^2}{\hbar c}\right)^2.$$

Nuclear densities n are of the order $0.01\ (mc/h)^3$, and in the core of neutron stars $n\simeq(mc/h)^3$. Omitting a numerical coefficient from n and noting that $mc^2/\hbar=10^{24}$, $Gm^2/\hbar c=10^{-38}$, we obtain $w=10^{-52}\,s^{-1}=(10^{45}\,yr)^{-1}$.

This result can be obtained in a more intuitive manner by considering as effective capture cross section the square of the Schwarzschild radius of a particle with a given mass m: $\sigma=(Gm/c^2)^2$, $w=nc\sigma$. The next stage of our consideration may turn out to be an application of nonlinear field theory of gravitation in a flat space. One may think that at small distances the interaction increases as p_1p_2/r; setting $p_1\sim p_2\sim 1/r$ we are led to the singular potential $U\sim -r^{-3}$. We note that on account of the kinetic energy the particles acquire an energy of the order of the Planck energy and the characteristic size of the closed universe at the instant of its formation is also of the order of the Planck length, 10^{-33} cm. The fantastically small size of the Schwarzschild radius corresponding to the rest mass of the baryon (10^{-50} cm) does not enter directly into this calculation.

According to Gribov, the formation of a bound state with zero mass could be treated as a transition into the condensate (which appears in contemporary field theories), so that not only the rest mass of the state vanishes identically, but also the energy and momentum are identically zero for any motion.

On the other hand, assuming that the probability of the process is proportional to the Planck volume $l^3_{Pl}\propto G^{3/2}$ (Starobinskiĭ) and completing $G^{3/2}$ to the required dimension with powers of the mass, we obtain

$$w=\frac{mc^2}{\hbar}\left(\frac{Gm^2}{\hbar c}\right)^{3/2}=10^{-33}\,s^{-1}=(10^{26}\,yr)^{-1}.$$

This estimate may be highly exaggerated (in terms of w), both owing to the different power of G and the dimensionless numerical factors. Still, one is forced to the conclusion of the extreme importance of pushing the experiments further. The theory must take into account the parton or quark structure of the baryons and learn to calculate quantum jumps of the metric. Essentially, the problem whether the energy density in the particle is smeared out or has a delta-function singularity is decisive. Smeared-out masses could not be jointed together by gravitational forces. Thus the question is related to the asymptotic behavior of form factors in the limit of high momenta.[8-10] The difference lies in the fact that for gravitation the energy density rather than the charge density plays a role (the latter was discussed in the papers we quoted). Unfortunately it is still very far to an experimental approach to the momentum values (10^{28} eV) in which we are interested.

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