The asymptotic situation with completely similar successive cycles is described by Eq. (2) with the term $1/a^2$ neglected. The solution of Eq. (2) is of the form

$$a=a_n\left(\sin\frac{3}{2}a_0^{-1}t\right)^{2/3},\quad a_0=\left\{\frac{8\pi G}{3}|\varepsilon|\right\}^{-1/2}.$$

The maximal hyperbolic radius a_n of the n-th cycle is determined from the condition $\rho(a_n)=|\varepsilon|$, and is proportional to $\nu^{|n|/3}\to\infty$ for $|n|\to\infty$. The duration of each cycle is $T_A=2\pi a_0/3$. The densities of baryons, of leptons, and of entropy at corresponding times in successive cycles does not depend on $|n|$. The cycles closer to Φ are described by Eq. (2) with ρ neglected (except in relatively small intervals of time at the beginning and end of each cycle). Neglecting ρ, we have $a=a_0\sin(t/a_0)$, and the duration of each cycle is $T_I=\pi a_0$. The transition from the initial to the asymptotic situation is defined by the condition $\rho(a_0)=|\varepsilon|$, and will occur at cycle number $n_2>n_1$ (on the assumption that at present $\rho<\rho_c$). The baryon asymmetry n_B/n_γ, however, already has its asymptotic value, since it is determined by the initial stage of the expansion of the Universe.

The stability of this pattern of successive collapses has not been investigated. In this paper we have discussed the "reversibility paradox," the hypothesis of cosmological CPT symmetry, and the various types of many-sheet models.

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On searches for new long-range forces

L. B. Okun'

Institute for Theoretical and Experimental Physics, Moscow

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The hypothesis of existence of long-range forces in addition to gravitational and electromagnetic forces is discussed. It is assumed that these forces act between so far experimentally undiscovered massive elementary particles of a new type. Proposed searches for such particles can be carried out by means of exact and systematic gravimetric measurements both at the surface of the Earth and within the confines of the solar system.

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The 1970's are distinguished by the discovery of a large number of new elementary particles and of the gauge interactions among them. The existing theoretical models make it plausible to assume that as one probes deeper to shorter and shorter distances one will discover new types of particles and short-range forces. At the same time there is a widespread belief that in addition to gravitation and electromagnetism there are no other long-range forces in nature. The latter conviction seems to me to be insufficiently founded and should be subjected to an experimental verification from all sides. An example of long-range interactions was proposed in Refs. 1 and 2, where the hypothetical theta-interaction was introduced, having a macroscopic confinement radius, and it was shown that the existence of particles which have nonabelian interactions is not excluded by the existing experimental data. In the present paper we make some additional remarks regarding the observable consequences which the existence of particles having a new type of long-range interaction can lead to, both for the nonabelian (of the theton type) or abelian (of the photon type) cases.

The likelihood that the particles and interactions discussed below exist in reality seems today to be vanishingly small. Nevertheless, it seems reasonable to set up experiments to search for them, if such experiments do not require special expensive efforts, and can be achieved in the framework of already existing programs. Even if such searches should not lead to the discovery of new types of matter, they could considerably narrow down the space of reasonable possibilities.

For the remainder of this discussion it is convenient to introduce the following terminology. We shall call the known gauge fields (photons, gluons, intermediate vector bosons) fields of the type o, and shall denote them collectively by V_o; we call the usual quarks and leptons fermions of type o, and denote them by F_o. We shall call o-particles both the V_o and the F_o.

We assume that there exist as yet undiscovered gauge fields V_y, among them some with long-range action, fields which do not interact with the o-particles. We call fermions which interact only with the

V_y-fields y-fermions and denote them by F_y. The V_y and the F_y will be collectively called y-particles. By definition the y-particles do not interact with the V_o fields.

We assume further that there exist particles which interact both with the fields V_o and with the fields V_y. These particles (which we designate as x-particles) represent a sort of bridge between the o- and y-worlds. (In the case of the theta-interaction[1,2] the y-particles are the thetons and the x-particles are the theta-leptons and theta-quarks.)

We shall assume that the worlds o and y exhibit a common gravitational interaction. Such a universal character of gravitation follows from the conservation of the energy-momentum tensor if the x-bridge exists. In the absence of an x-bridge a discussion of a y-world completely isolated from the o-world seems to be devoid of physical meaning[1)] (see Ref. 3).

As was remarked in connection with the theta-particles in the preceding papers,[1,2] there exist serious experimental limitations on the abundance of x-hadrons and electrically charged x-leptons in the matter that surrounds us. For electrically neutral x-leptons these bounds are considerably poorer (cf. Ref. 4). As regards the y-particles, their total mass in the Universe may exceed by one order of magnitude the mass of the o-particles and is restricted only by the known data on the Hubble constant for the expansion of galaxies.

It is not excluded that the y-matter, if it exists, makes up the "hidden" mass of the galactic haloes, double galaxies, groups and clusters of galaxies (for a brief discussion of missing mass and references to the literature, cf. Ref. 5). The global density of hidden mass apparently exceeds by several factors the density of visible mass.

Large accumulations of absolutely transparent y-matter could serve as ideal gravitational lenses, producing so-called gravitational mirages (the possibility of existence of such mirages has been discussed recently in connection with the observation of twin quasars[6]).

A double "stellar" system in which both components are y-stars, should it exist not too far from us, could be detected by its gravitational radiation. If a y-star surrounded by several o-stars would have a size comparable to the size of the system, one could detect observable deviations from Kepler's laws. Black holes consisting of y-matter are, of course, completely identical to black holes consisting of o-matter, and even evaporation of black holes y-particles should be emitted in addition to o-particles.

Within the confines of the solar system there could remain unobserved gas made up of y-matter, and even whole y-planets. The existence of the latter could manifest itself through the gravitational perturbations on the orbits of the usual planets. As is well known, there is an unknown source of perturbations of the motions of Neptune, Pluto, and Halley's comet. There were even attempts to explain these perturbations by means of the existence of a tenth planet with a mass of the order of that of Jupiter, and situated at a distance of 60 astronomical units from the Sun.[7] Searches for such a planet were not crowned by success. Moreover, it was shown by later more accurate calculations[8] such that a planet would not improve the agreement between theory and observations.

One can judge the general accuracy of calculations and observations, for instance, by the data on the precession of the perihelion of Mercury. It is known (cf. e.g., Ref. 9) that the observed precession equals 5600 $\pm 0.41''$/century. Out of this quantity approximately $5025''$/century are accounted for by the rotation of the astronomical coordinate system tied to the Earth, $532''$/century are related to Newtonian gravitational perturbations, mainly due to Venus, Earth, and Jupiter. The remaining $43.11 \pm 0.45''$/century are compared to the value predicted by general relativity theory: $43.03''$/century.

Searches for y-matter near the Sun could be carried out by means of sensitive gravitational variometers[10,11] (the sensitivity of variometers reaches values of 1 eötvös $= 10^{-9}\,c^{-2}$). It seems that the easiest way to exclude the existence of y-spheres around the Earth and the Sun is by means of gravimetric measurements from satellites.

If a massive y-sphere existed inside the Earth, being coupled to the Earth only by gravitational attraction, this would lead to periodic ($T \sim 1.5$ hours, the period of a satellite) variations of the gravitational force on the Earth. (The present-day accuracy of measurements of such short-period variations is $\sim 10^{-9}$.)

So far we have discussed only free y-matter. In the presence of x-particles the y-matter could combine chemically with ordinary matter, since the x-particles, "sticking" to atomic nuclei, could enter into the formation of some peculiar atoms (see the discussion of theta-fermions, Ref. 2). If one assumes that the forces between y- and x-matter are not weaker than the usual chemical forces, one is easily led to the conclusion that 10^3 x-particles suffice in order to bind at the surface of the Earth one gram of y-matter.

If one assumes that the x-particles carry some kind of Abelian charges and that the coupling constant to the corresponding V_y-"photons" is of the order of α, then experiments of the Eötvös type yield the following bound on the average concentration of x-particles in matter: $n_x \lesssim 10$ x-particles/gram. This estimate does not take into account the possible neutralization of the y-charge of the Earth by y-charges of opposite sign. The upper bound following from Cavendish-type experiments is approximately by three orders of magnitude larger. Taking into account the possible accumulation of x-particles in biological objects, it would be interesting to carry out Eötvös type experiments on biological samples. We also note that self-organization of y-matter could lead to a quite nonuniform distribution of x-particles in the matter which surrounds us.

It is not hard to generalize the model discussed here, considering not only one y-world, but a whole series of worlds y_i, each characterized by its own long-range forces, and coupled to the o-world by "bridges" of massive particles x_i and with the y_j worlds by the bridges x_{ij}. The most stringent bounds on the parameters of such a picture come from cosmology based on the theory of the hot Universe (the big-bang model).

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[1)]We shall not discuss here the fantastic version in which there exists a world z, at present completely isolated from our world and having its own gravitons. The coupling to the z-world could have disappeared as a result of a peculiar phase transition above the Planck temperature.

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Calculation of the energy levels of μ-mesic molecules of hydrogen isotopes in the adiabatic representation of the three-body problem

S. I. Vinitskiĭ, V. S. Melezhik, L. I. Ponomarev, I. V. Puzynin, T. P. Puzynina, L. N. Somov, and N. F. Truskova

Joint Institute for Nuclear Research, Dubna
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The energy levels ε_{Jv} of the mesic molecules $pp\mu$, $pd\mu$, $pt\mu$, $dd\mu$, $dt\mu$, and $tt\mu$ in the states (Jv) of the rotational and vibrational motion are calculated. The calculations are made in the adiabatic representation of the three-body problem, in which the wave function of the μ-mesic molecule is expanded with respect to a complete set of solutions to the quantum-mechanical two-center problem. A numerical investigation was made into the rate of convergence of the expansion. For the weakly bound states ($J = 1$, $v = 1$) of the mesic molecules $dd\mu$ and $dt\mu$ the values $\varepsilon_{11}(dd\mu) = -1.91$ eV and $\varepsilon_{11}(dt\mu) = -0.64$ eV were obtained.

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1. INTRODUCTION

At the Laboratory of Nuclear Problems at the Joint Institute for Nuclear Research, Dubna, an experimental measurement was recently made[1] of the rate of formation $\lambda_{dt\mu}$ of the mesic molecules $dt\mu$ and the lower bound $\lambda_{dt\mu} > 10^8$ sec^{-1} was obtained. According to the calculations of Ref. 2, the high rate of this process is due to the resonance mechanism of formation of the mesic molecules $dt\mu$ in the weakly bound rotational-vibrational state with quantum numbers $J=1$, $v=1$. The binding energy of this state, $\varepsilon_{Jv} \approx 1$ eV, was calculated earlier[2] for the first time by perturbation theory realized in the adiabatic representation of the three-body problem.[3-7]

For the detailed study of μ-mesic molecular processes in a mixture of hydrogen isotopes and, in particular, to describe the process of resonance formation of the mesic molecules $dt\mu$, it is necessary to know their energy levels to an accuracy ~0.01 eV, which is ~10^{-6} mesic-atomic energy units $\varepsilon_\mu = 2m_\mu$Ry $= 5626.51$ eV.[2]

In the present paper, we present the results of calculations of the energies ε_{Jv} of various (Jv) states of μ-mesic molecules of the hydrogen isotopes. The calculations are made in the adiabatic representation of the three-body problem, in which the wave function of the μ-mesic molecule is expanded in a complete set of solutions to the quantum-mechanical two-center problem.[3-5] In this approach, the original eigenvalue problem for the nonrelativistic Schrödinger equation in a six-dimensional space reduces to the solution of a Sturm-Liouville problem for a system of ordinary integro-differential equations. The matrices of the coefficients of this system (the effective potentials of the three-body problem in the adiabatic representation) are calculated with the necessary accuracy by means of the algorithms of Refs. 8–13.

The corresponding Sturm-Liouville problem is solved numerically with the required relative accuracy in the framework of the continuous analog of Newton's

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