Unfortunately, it cannot be stated a priori that the lifetime will be rather large because of the large difference between the energies of the metastable phase and the molecular phase at $p = 0$ (the metallic phase is found to be stable against decay to atomic hydrogen) and because of the small mass of the hydrogen or deuterium ions. A factor that contributes appreciably to stabilization is the large difference between the densities of the two phases. Accordingly, the question as to the real density dependence of the molecular-phase energy may become critical.

The basic results set forth in the paper will be found in[4].

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V. B. Braginskiĭ and V. I. Panov. The Equivalence of Inertial and Gravitational Masses.

The general theory of relativity was based on a fundamental experimental fact—the equality of the ratio of the inertial and gravitational masses for different bodies (the equivalence principle). The authors repeated the experiment in which this equality was determined for aluminum and platinum. The experimental setup of Dicke, Krotkov, and Roll[1] was preserved in the experiment. A torsion pendulum, falling with the earth into the gravitational field of the sun, should be acted upon by a mechanical torque proportional to the expected difference between the accelerations of the substances of which the pendulum consists (if the equivalence principle is violated). Owing to the earth's rotation, this torque should vary sinusoidally with a period of 24 hours. The sensitive element in the experiment was a torsion pendulum with an oscillating period of 2×10^4 sec (5 hours 20 minutes) and a relaxation time greater than 6×10^7 sec.

It was shown in[2] that an oscillator with a large relaxation time can be used to measure a disturbance far below the level of stationary thermal fluctuations corresponding to an energy kT. The setup made it possible to resolve an acceleration difference smaller than 1×10^{-13} cm/sec^2 during a measurement time of 6×10^5 sec against the thermal-fluctuation background. Recognizing that the acceleration difference between aluminum and platinum was measured in the gravitational field of the sun ($g = 0.62$ cm/sec^2) in the experiment, the thermal fluctuations could simulate violation of the equivalence principle at a level below 5×10^{-13}.

The pendulum was placed in a vacuum chamber in which the pressure ($< 1 \times 10^{-8}$ Torr) did not change during the time of the experiment. The arm of the pendulum was suspended on an annealed tungsten wire 2.8×10^2 cm long and 5×10^{-4} cm in diameter. To reduce the influence of local variable gravitational-field gradients, the pendulum was built in the form of an eight-pointed star with a radius of 10 cm and equal masses at the points. Two groups (four each) of these masses were made from specially purified aluminum and platinum. The total mass of the weights was 3.9 g. The setup was placed in a thermostat. The temperature around the setup was stabilized to within 5×10^{-4}°C. The arm of the pendulum was protected by a magnetic shield. The pendulum's oscillations were registered on photographic film by a flying spot. A helium-neon laser was used as the light source. The length of the optical lever was 5×10^3 cm. Violation of the equivalence principle at the 1×10^{-12} level would have produced a harmonic in the motion of the pendulum with a one-day period and an amplitude of 1.8×10^{-7} rad, which would correspond to a 9×10^{-4} cm displacement of the spot on the film. After reduction of the measured data, the average amplitude of the pendulum's diurnal oscillations was found to be $(-0.55 \pm 1.65) \times 10^{-7}$ rad (at the 0.95 confidence level). It can therefore be stated that the ratios of the inertial and gravitational masses for aluminum and platinum are equal to within 0.9×10^{-12}. It is seen from the results that the expected sensitivity was not attained. This means that the principal disturbing factors operating during the measurements were simulating effects, including primarily the following:

1) The influence of local variable gravitational-field gradients.

2) Variations of the radiometric pressure.

3) Variations of the magnetic field in the laboratory.

4) Light pressure from the registration-system source.

5) Seismic jolts.

Analysis of the experiment and control measurements make it possible to state that the basic contribution to the error of measurement comes from seismic jolts combined with the light pressure of the laser.

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Ya. B. Zel'dovich, L. P. Pitaevskiĭ, V. S. Popov, and A. A. Starobinskiĭ. Pair Production in a Field of Heavy Nuclei and in a Gravitational Field.

As quantum mechanics developed, it became clear very quickly that it not only changed the laws of particle motion, but also implies a theory of their production. In principle, this became clear when Einstein showed that light consists of quantum particles or photons. The quantum theory of systems with variable numbers of particles was developed in the classical works of V. A. Fock. The processes of particle production and annihilation have been thoroughly studied. Why, then, should we return to this problem today?

1. To this day, the production of pairs by photons has been possible in experiment only with high-frequency quanta ($\hbar\omega \geq 2mc^2$). The day is approaching when it will be possible to accomplish experimentally a process of a qualitatively different kind—the production of pairs

of charged particles in a static field—in the field of a superheavy nucleus or in an almost static field in the focus of a laser.

2. The problem of particle production is a pressing one in astrophysics. A few years ago, the discovery was made that relict radio emission fills the Universe with a density of the order of 10^8—10^9 photons per nucleon. The properties of the radiation indicate that these photons were not created by the usual mechanisms (synchrotron radiation, etc.): they have either existed for all eternity (like baryons) or were produced at an early stage in the evolution of the Universe, near the singularity. A universal mechanism of particle production by gravitational fields might have been in operation here. Such a theory might perhaps explain yet another mystery of the Universe: its uniformity and isotropy. A potential difference $e(\varphi_1 - \varphi_2) \geq 2mc^2 = 1$ MeV per $e^\pm$ is necessary for the production of a pair of charged particles in an electrostatic field. Much larger values $V(0) = 3Ze^2/2R \approx 1.6Z^{2/3}$ MeV are attained in heavy nuclei (thus, $V(0) = 30$ MeV in the uranium nucleus, and at $Z = 170$, $V(0) \sim 50$ MeV), but only in a region of space that is small by comparison with $\hbar/mc$, so that the lower level of the electron does not coincide with the bottom of the potential well.

Particle production becomes possible only after the electron ground level 1S has crossed the boundary of the lower continuum: $E = -mc^2$, i.e., when the electron has a binding energy $\epsilon > 2mc^2$ (we note for comparison that $\epsilon = 130$ keV for uranium). This occurs at $Z = Z_c \approx 170$ (account is taken of the finite dimensions of the nucleus; for a point nucleus, we would have $Z_c = 137$). The problem was first examined by I. Ya. Pomeranchuk and Ya. A. Smorodinskiĭ. At $Z > Z_c$, the 1S level vanishes from the single-particle discrete solutions of the Dirac equation, but the characteristic distortion of the lower-continuum wave functions, which is concentrated in a narrow region of energies around a certain energy $E = E_0 < -mc^2$, makes its appearance. This distortion yields an additional vacuum charge density analogous to the K shell in an atom with $Z > Z_c$ and carrying a total charge $-2e$. At $Z > Z_c$, the bare nucleus Z produces two positrons and "attracts" a K shell, which screens the charge Z to $Z - 2$, from the vacuum. This system (a supercritical atom) has chemical properties very closely similar to those of an ordinary atom, but there are also differences. They are manifested in resonant nonradiative scattering of positrons (at energies near $-E_0$) and in a photoeffect (a sharp spike in the spectrum of the e^-, e^+ pairs at $\hbar\omega > mc^2 - E_0$ for an electron energy $E_- = E_0 + h\omega$). Observation of certain effects is also possible on collision of two (bare) uranium nuclei, when an electric field corresponding to the doubled charge $2Z = 184 > Z_c$ forms as the nuclei approach one another. To analyze the kinetics of the process, it is necessary to calculate the probability of pair production in an alternating electric field. Such problems were recently examined (A. I. Nikishov, V. S. Popov).

In the classical interpretation, an electron and a positron are produced at different points in space 1 and 2, so that $e(\varphi_1 - \varphi_2) = 2mc^2$, where φ is the electrostatic potential. Correct description of pair production is possible only in quantum theory and is inseparable from the polarization of vacuum. For example, when an electric field E is switched on, the current density j is proportional to E, the energy density ϵ is proportional to E^2, and the relation $|j| > e\epsilon/mc$, which prevails for an aggregate of real particles (for them, $j = nev$, $\epsilon = nmc^2/\sqrt{1-\beta^2}$), is violated. The differing behavior of j and ϵ results from the fact that a vacuum is an eigenstate with $\epsilon = 0$, while $j = 0$ only in the sense of the average value.

Both charged and neutral particle pairs can be produced in a gravitational field. A potential difference $\Delta\varphi$ of the order of c^2 is necessary for pair production in a static gravitational field. In the presence of such strong fields, it is necessary to employ the general theory of relativity and consider the processes in a curved Riemann space. Let us turn at once to a synchronous metric with interval $ds^2 = dt^2 - a^2(t)dx^2 - b^2(t)dy^2 - c^2(t)dz^2$, which is homogeneous and three-dimensionally-plane. For correct formulation of the quantum problem, it is necessary to assume that the metric becomes four-dimensionally-plane as $t \to -\infty$. For the boson field, the classical theory is the exact asymptotic limit of the quantum theory for a large number of particles. Owing to the homogeneity of the three-dimensional space, the momentum of the field is preserved, and only the time dependence of the plane-wave amplitude remains nontrivial.

Physically, the production of pairs in this metric is analogous to the phenomenon of paramagnetic resonance, since the field oscillators are excited by a change in their frequency and not by an external inhomogeneous periodic force. As in an electric field, particle production is inseparably related to the polarization of vacuum. A simple, finite, and unambiguous answer was obtained for the final state in the case of a metric coinciding with the plane Minkowski metric at $t = \pm\infty$. The problem of collapse and emergence from the cosmological singularity is more complex (it involves renormalization). L. Parker showed that particles are not produced in the isotropic case ($a = b = c$) if their mass $m = 0$ or $m \to \infty$. The result for $m = 0$ is explained by the fact that the selected metric is conformally-plane in the isotropic case, while the field equation is conformally invariant at $m = 0$. In the case of isotropic collapse ($a(t) \sim |t|^q$ as $t \to 0$; $0 < q < 1$), the energy of the produced particles depends on violation of conformal invariance at $m \neq 0$ and increases like $m^4|mt|^{-4q}$ when $|mt| \ll 1$ (here $\hbar = c = 1$). If $a(t) \sim \sqrt{|t|}$ (this metric is created by external matter with the equation of state $p = \epsilon/3$), then the ratio of the energy of the produced particles to the energy of the external matter is of the order of $Gm^2/\hbar c$, i.e., very small. The result for an anisotropic universe, e.g., one of the Kasner type ($a \sim t^{q_1}$, $b \sim t^{q_2}$, $c \sim t^{q_3}$; $q_1 + q_2 + q_3 = 1$, $q_1^2 + q_2^2 + q_3^2 = 1$), which is not conformally plane, is most interesting. It follows from dimensional analysis that when $|t| \ll \hbar/mc^2$, the energy density of the particles being produced is proportional to $\hbar/c^3t^4$. We may therefore expect the energy-momentum tensor of the pairs to become dominant in the equations at small t, with a tendency to isotropization. In order of magnitude, this will occur with a characteristic time 10^{-44} sec, derived from G, $\hbar$, and c. The next unsolved problem is that of consistent analysis of anisotropic collapse with determination of the exact magnitudes and signs of the energy and pressure in three axes and with consideration of the reciprocal influence of the newly produced matter on the metric. Finally, we take note of problems that constitute parts of the general problem but require new ideas: 1) general covariant formulation of the theory; 2) consideration of the direct, nongravitational interaction of the particles with one another; 3) the most difficult and important problem: the cosmological problem of emergence from the singularity, of the formulation of initial data in the singular state. It is possible that this last problem will be inseparable from the general problem of quantization of the metric.

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A. B. Migdal. Vacuum Stability and Limiting Fields. In studies of the polarization of vacuum, the field, in which there are deep bound particle states, is usually left out of consideration. In this paper, we discuss the phenomena that arise when a strong external field leads in the single-particle problem to the appearance of a bound state with energy approaching the energy of formation of particles from the vacuum.

The best-known examples of the appearance of such critical levels are the point nucleus with charge $Z_c = 137$ and the finite nucleus of radius $R = r_0A^{1/3}$ with charge $Z_c = 170$. It can be shown that when $Z > Z_c$, the state with the lowest energy corresponds to an energy with a charge. This charge is situated in the region $\hbar/mc$. Owing to the Pauli principle, which forbids accumulation of particles in a dangerous state, a weak screening field appears. A more important reconstruction of the vacuum occurs in the fields in which production of Bose particles is possible. Consideration of the interaction between particles guarantees stability of the vacuum. Owing to the existence of the Bose particles, the effective field cannot exceed the value at which the critical particle-energy value is reached.

A particularly interesting effect appears in the field realized in nuclear matter. The field acting on mesons in nuclear matter is determined by the formula $V = 4\pi nf$, where n is the nucleon density and f is the amplitude of zero-angle scattering of the π-meson. At a sufficiently high density n (when $V > \mu^2c^4$), the meson vacuum is reconstructed and a phase transition occurs in which the equation of state of the nuclear matter changes. This phase transition can apparently be accomplished in neutron stars, in the region of high neutron density. In ordinary nuclei, the dense phase is separated from the ordinary phase by an enormous potential barrier. Attempts might be made to find such superdense nuclei in cosmic rays. The charge-to-mass ratios of such nuclei are substantially higher than the ordinary.

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