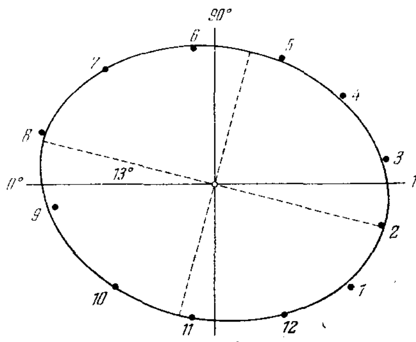

FIG. 1

1922 to 1935, in Italy from 1935 to 1961, and again in Japan since 1962. During this time, the observation programs and reduction methods were modified several times, and the work of some of the stations was temporarily interrupted. There is therefore no fully uniform material for investigation of the general laws governing the motion of the poles, but, by way of an approximation to it, Vicente and Yumi last year published a paper containing a list of the pole's rectangular coordinates from 1900 through 1969, referred to the so-called conventional international origin—the point at which the mean North Pole, i.e., the pole after removal of periodic motions, was situated in 1900—1905. The list contains coordinates of the mean pole for the middle of each month during the period stated, expressed in hundredths of a second of arc accurate to 0″.001, which corresponds to 3 cm on the surface of the earth. An analysis of this wealth of material that was carried out at Pulkovo Observatory yielded the following results.

1. It brought out clearly a secular motion of 0″.0033 per year, which corresponds to 10 cm, in the direction of the 76th meridian of western longitude.

2. Superimposed on this approximately uniform motion is a periodic annual motion along an elliptical path with semiaxes 0″.081 = 250 cm and 0″.064 = 200 cm, with the major axis directed along the 13th meridian of western longitude. This ellipticity indicates inequality of the earth's principal equatorial moments of inertia and is probably related to a certain slight ellipticity of

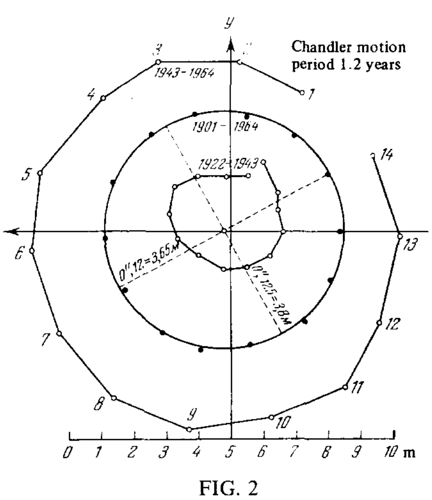

FIG. 2

the earth's equator. This motion with one-year period is caused by meteorological factors, chiefly the deposition of snow and ice on the continents and the enormous air masses over north-eastern Asia in winter.

3. The 14-month or Chandler period is that of the earth's natural wobble on its axis due to noncoincidence of the axis of rotation with the axis of inertia. This vibration decays and then increases again, and has, on the average, traced out a nearly circular ellipse over 66 years, with semiaxes 0″.125 = 3.8 m and 0″.120 = 3.65 m. Different authors have estimated the relaxation time of these vibrations at 10 to 30 years, but it appears to be close to 20—25 years, and a new excitation of the damping vibrations requires some sort of disturbance, which has been sought in catastrophic earthquakes or volcanic eruptions, although the latter are too weak to account for the effect.

As for the secular motion of the poles, it is intriguing to compare it with the action of the force that arises as a result of the earth's rotation and tends to shift the continents toward the equator. This force is proportional to the elevation of the particular land area above sea level and to the sine of the doubled latitude, so that it vanishes at the pole and the equator and reaches its maximum values at the latitudes ±45°. If the earth's crust shifted as a single whole on the underlying magma, the resultant of all such forces would tend to rotate it from north to south in the direction of the 97th meridian of eastern longitude. The North Pole would then move in the opposite direction relative to the crust, i.e., 83° W, which is very close to what is observed. The various continents pull the crust in different directions, but the action of the vast Tibetan Plateau, the highest on earth, predominates. If this is the cause of the secular motion of the pole, the past history of this motion should be the same as its history over the past 70 years, and it should continue into the future as long as there are no substantial changes in the relief of the continents.

Yu. Kagan and E. G. Brovman. The Problem of Metallic Hydrogen.

Interest in the problem of metallic hydrogen was originally related chiefly to astrophysical problems. The pioneering work of Wigner and Huntington (1935) was followed by publication of a whole series of papers in which attempts were made to find the equation of state and to analyze the physical properties of metallic hydrogen at extremely high densities. A. A. Abrikosov[1] made an important contribution to the elaboration of these problems.

Recently, however, the problem has acquired a purely "earthbound" interest. This has been due basically to three circumstances.

First, it was suggested that metallic hydrogen should be a superconductor with a high transition temperature. This statement has some basis in reality in view of the high values of the characteristic phonon frequencies (the small mass of the ion) and the relatively large electron-phonon interaction constant (the absence of an ionic core). Secondly, the hope was voiced that the metallic phase of hydrogen would have a metastable state. Thirdly, the development of the physics and technique of high pressures made it realistic to pose the problem of producing, in the very near future, the enormous pressures necessary for the transition from the molecular to the metallic phase.

A second problem must be singled out here. It is readily understood that the existence of a sufficiently long-lived metallic phase of hydrogen at zero pressure would be of cardinal importance for numerous "earthbound" applications.

Analysis of the problem of the metastable metallic phase of hydrogen presupposes solution of a whole series of interrelated problems:

1. Finding the energy of the metallic state of hydrogen and proving the existence of stationary points with respect to all parameters of the phase, including volume, as well as determination of the structure to which the absolute energy minimum corresponds.

2. Proof of dynamic stability, both in the long-wave limit (uniform deformation) and in respect to excitations with arbitrary wavelength (the reality of the phonon-spectrum frequencies for the entire momentum space).

3. Finding the equations of state for various crystalline phases and establishing the relation between the structure obtained under pressure from the molecular phase and the structure of the metastable phase at pressure $p = 0$.

4. Determination of the lifetime of the metastable state.

For analysis of the first three problems, we have employed the results of a previously developed multiparticle theory of metals[2], application of which to analysis of specific nontransition metals resulted in good quantitative agreement with the experimental data for a broad range of static and dynamic properties, including both the equation of state over the entire accessible interval of pressures and the phonon spectrum throughout the phase volume.

Use of these results for the case of metallic hydrogen is made easier by the absence of ionic-core overlap and of uncertainty as to the value of the electron-ion interaction, which is now of purely Coulomb nature, so that only the universal constants appear in the problem.

The energy of the metallic phase of hydrogen was analyzed as a function of the continuous structure parameters (unit-cell parameters). Here the problem was analyzed over the entire parameter region for cubic, uniaxial, and rhombic lattices (for all 11 Bravais lattices) and for known diatomic structures of the diamond and β-Sn types and the close-packed hexagonal structure. The Monte Carlo method was used in a six-dimensional parameter space for structures of lower symmetry.

Analysis of the results obtained indicated the following:

1) The presence of a region of intermediate densities $r_s \sim 1.7$, where $p = 0$ and compressibility is positive, is characteristic for the metallic phase of hydrogen.

2) All cubic structures are unstable with respect to shearing deformations at $p = 0$.

3) Only the strongly anisotropic structures are mechanically stable in principle.

4) Anisotropy gives rise to families of structures in which there are practically no energy barriers between different structures of the same family and the structures themselves merge into one another by definite types of deformation. Naturally, the corresponding elastic modulus is near zero.

5) The absolute minimum is realized on the "triangular" family of structures, which is the set of structures obtained from the simple hexagonal lattice if the sites are shifted parallel to the c axis (z axis) while preserving the hexagonal projection onto the x, y plane and the distance between sites along z (the distance between ions on the x, y plane is markedly larger than the distance between them along z). Next higher in energy is the "square" family, which is obtained from the simple tetragonal lattice by a deformation of the same type.

6) Leaving aside the elastic modulus corresponding to the deformation that generates the family, these structures exhibit long-wave stability.

Analysis of the phonon spectrum over the entire phase space indicated that structures of the triangular family possess full dynamic stability. Consideration of the zero-point oscillations has as a consequence that the triangular (and, by analogy, the square) family of structures appears to become the only structure that loses crystalline symmetry along the z axis but preserves the strict triangular lattice in the x, y plane. As a result, we arrive at a three-dimensional substance with two-dimensional order. Interestingly, thermal fluctuations at $T \neq 0$ do not disturb such a two-dimensional structure. This was first demonstrated by Landau (see[3]).

Thus, the possibility of the existence of a hydrogen metallic phase at $p = 0$ that is stable within the framework of the metallic state and, to all appearances, possesses a highly unique structure must be regarded as established in principle.

With the object of analyzing the properties of the metallic state under pressure, the equations of state were found for the various crystal structures and the phase diagram determined with the thermodynamic potential and pressure as coordinates ($T = 0$). With increasing pressure, the anisotropy of the energywise favored structures decreases owing to the increasing relative importance of the ionic lattice. In the limit of astronomical densities, the lowest energy corresponds to the symmetrical FCC and HCP-type lattices, which become stable at high pressures. Phase transitions take place between the various metallic structures at intermediate densities, e.g., at comparatively low pressures a transition takes place from the "compressed" structures ($c/a < 1$) corresponding to the triangular and square families to "stretched" structures ($c/a > 1$), among which the rhombohedral lattice comes to be that with the lowest energy as the pressure increases. The transition from the molecular to the metallic phase under pressure will take place in one of the stretched structures. However, the wide scatter of the results for the molecular phase makes it impossible to estimate the transition pressure with any confidence. Thus, using only recent papers as a basis, we can obtain values ranging from 3 megabars to 1 megabar.

It should be noted that metallic hydrogen under pressure exhibits liquid tendencies. In the case of stretched structures, this results from the relatively free slip of the crystal planes parallel to another. In view of this, the possibility that the transition from the molecular phase will be to a liquid-metal phase cannot be entirely excluded.

The question as to the lifetime of the metastable state remains open. (This time is finite even at $T = 0$ owing to quantum effects.)

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