Some Macroscopic Effects of a Geometric Scheme for the Violation of CP-Invariance

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Submitted July 17, 1972

Zh. Eksp. Teor. Fiz. **62**, 444–453 (February, 1972)

The hypothesis is advanced that the observable time-irreversibility (and the violation of CP-invariance) is also related to noninvariance with respect to time-translations, leading to energy nonconservation effects. This assumption is realized in a scheme with geometrized electromagnetic field which was proposed previously for the interpretation of CP-noninvariance. Several consequences are discussed, and it is shown that for values of the fundamental parameter equal to $l \approx 10^{-17}$ cm the scheme does not lead to any contradictions.

1. INTRODUCTION

THE problem of CP-nonconservation which appeared in 1964 together with the discovery of the two-pion decay of the long-lived neutral K meson[1], has remained unsolved up to this time, and raised a series of fundamental questions for physics. The most important of these is related to the properties of space-time. Indeed, the hypothesis of CP-invariance[2] was introduced, essentially, on the basis of geometric considerations. The most consistent motivation was given by Wigner[3], which, in brief, boils down to the following. From the properties of space-time (the pseudoeuclidean Minkowski space) it follows that the operation $\hat{P}$ of reflection of the space coordinates commutes with the time-translation $\hat{\Delta}_t$:

$$[\hat{\Delta}_t, \hat{P}] = 0.$$

To the operation $\hat{\Delta}_t$ corresponds the total Hamiltonian of the system, consequently, the equation means that there must exist a conserved operator, corresponding to the spatial reflection $\hat{P}$. After the discovery of parity nonconservation it became clear that the parity operator P is not suitable for this purpose, and it was proposed to consider that to the reflection of space corresponds the product of the operators P and the operator C, describing charge conjugation, i.e., the operator CP. At present there are no other possibilities[1)]. The nonconservation of CP shows that there must be some flaw in the reasoning or in the assumptions. These arguments have led to a search for the explanation of violation of CP-invariance within the framework of a geometry differing from the usual one. In particular a geometric interpretation of CP-violation was proposed[5,6], based on the introduction of a torsion of space in the presence of an electromagnetic field. A modification of the geometry leads to the appearance of new forces and interactions which violate CP invariance, as well as the invariance with respect to time-reversal T.

Obviously, a modification of the geometry is a sufficiently radical step, and its consequences are not limited to the violation of CP- and T-invariance. In particular, for particles moving in an electromagnetic field, there will appear, in general, a nonconservation of energy. This is at a first glance a rather unpleasant feature, but in a geometric scheme is not at all unexpected. Indeed, from a theoretical point of view, the conservation of energy is a consequence of the temporal homogeneity of Minkowski space. On the other hand, as already mentioned, the conservation of CP-invariance also follows from the properties of Minkowski space, moreover, with the same degree of certainty (i.e., with complete rigor) as the conservation of energy. Such considerations allow us to express the hypothesis that at the same level as CP-violation manifests itself, one can expect a violation of energy conservation. As an analogy one should remember that the time-irreversibility of a statistical nature is always accompanied by a dissipation of energy.

The problem of finding conserved quantities in geometric theories, e.g., in general relativity, always presents certain difficulties. It is possible that in the model under discussion, although the usual energy is not conserved, there is another conserved quantity, which generalizes the energy concept, but that so far we have been unable to construct this quantity. In the present paper we discuss possible effects of energy nonconservation[2)] in strong electromagnetic fields. It turns out that such effects are small and therefore the model we discuss does not contradict the accumulated evidence on the high degree of energy conservation observed under laboratory conditions, as well as in astrophysical observations. We give some estimates below, but start with the fundamental assumptions.

2. ENERGY NONCONSERVATION IN A SCHEME WITH GEOMETRIZED ELECTROMAGNETIC FIELD

We first list the necessary expressions from[6] and show that the nonconservation of energy in electromagnetic fields indeed occurs in the case under consideration.

A scheme with geometrization of the electromagnetic field was proposed[5,6] in order to explain the violation of CP-invariance and its basic idea consisted in the following: the affine connection coefficients L^i_{jk} (Christoffel symbols) are determined not only by the gravitational field (i.e., by the metric tensor g_{ij}), but

[1)]We do not discuss here the hypothesis of existence of a "mirror" world, which has been discussed critically, e.g., in the paper by Kobzarev, Okun', and Pomeranchuk[4].

[2)]The problem of nonconservation of energy has been posed before. From different points of view this problem was considered by various authors (cf., e.g.,[7,8]).

also by the electromagnetic field E_{ij}. The expression for these coefficients is uniquely determined, and for the case of the absence of a gravitational field ($g_{ij} = \delta_{ij}$) has the form (in Cartesian coordinates)

$$L_{ml}^{n} = (\delta_{k}^{n} + F_{\cdot k}^{n\cdot})\,\partial_l F_{m\cdot}^{\cdot k}, \tag{1}$$

where

$$F_{\cdot k}^{n\cdot} = \delta^{nl} F_{lk}, \quad F_{m\cdot}^{\cdot k} = \delta^{kl} F_{ml},$$

and F_{ml} is a tensor satisfying the condition

$$(\delta_s^{k} + F_{\cdot s}^{k\cdot})(\delta_l^{s} + F_{l\cdot}^{\cdot s}) = \delta_l^{k}, \tag{2}$$

and thus having six independent components. The tensor F_{mn} can be related to the electromagnetic field in the following manner

$$\tfrac{1}{2} e (F_{mn} - F_{nm}) = \pm l_0^2 E_{mn}. \tag{3}$$

Condition (2) allows us to construct the tensor completely in terms of its antisymmetric part (3) (cf.[5,6]). The definition (3) contains a new constant l_0 of dimension length, which determines the degree to which the geometry is modified in the presence of an electromagnetic field (in Eq. (3) e is the absolute value of the electronic charge).

It is clear that the value of l_0 and the sign in Eq. (3) can only be determined experimentally, however, one can draw some conclusions on the possible magnitude of l_0 by correspondence with the existing models for CP-violation. As was shown in the previous papers[5,6], the geometrization (1) of the electromagnetic field leads to the appearance of CP-noninvariant interactions of particles with the electromagnetic field, with the coefficient l_0^2/e playing the role of coupling constant. As is well known, in order to explain the fundamental effect—the decay $K_L \to 2\pi$—two models have been proposed which are closely related to the electromagnetic field: the electromagnetic CP-violation[9] and the weak-electromagnetic version of CP-violation[10,11]. In the first case the order of magnitude of l_0 is estimated from the correspondence (in units of $\hbar = c = 1$)

$$e/m^2 \approx l_0^2/e, \quad l_0 \approx e/m \approx 10^{-14} - 10^{-15}\,\text{cm}, \tag{4}$$

where m is some characteristic mass. For the case of the weak-electromagnetic violation

$$eG \approx l_0^2/e, \quad l_0 \approx eG^{1/2} \approx 10^{-17} - 10^{-18}\,\text{cm}, \tag{5}$$

where G is the weak interaction constant.

It is to be understood that the expressions (4) and (5) give only possible values of the order of magnitude of l_0 for the corresponding cases. As regards the electromagnetic CP-violation, the extremely low experimental value of the neutron electric dipole moment ($d_n \lesssim 10^{-23}$ e-cm) leads to serious contradictions, so that with good likelihood this version is ruled out experimentally. The weak-electromagnetic version does not contradict any experimental facts. In the sequel we shall return to the problem of possible values of l_0 from another point of view, and now we turn directly to the problem of energy nonconservation.

It is natural to assume[6], and one usually does, that in the modified geometry the motion of a test body not acted upon by external forces, including the usual electromagnetic Lorentz force, occurs along a geodesic line of the space, i.e., the equations of motion have the form

$$\frac{d^2x}{ds^2} = L_{jk}^{i} \frac{dx^j}{ds}\frac{dx^k}{ds} = 0; \tag{6}$$

where s is the proper time. (In the presence of external forces, the appropriate expressions have to be substituted into the right-hand side in place of zero.) Using the explicit expression of the affine connection (Christoffel symbols) in terms of the electromagnetic field, given by (1) and (3), and retaining only the first order terms in l_0^2/e, we obtain

$$\frac{d^2x^i}{ds^2} \pm \frac{l_0^2}{e}\frac{\partial E_{j\cdot}^{\cdot i}}{\partial x^k}\frac{dx^j}{ds}\frac{dx^k}{ds} = 0. \tag{7}$$

In this paper we shall consider only the nonrelativistic case, and therefore we write the nonrelativistic expression for the additional force appearing due to the affine connection

$$\mathbf{F} = \mp \frac{mcl_0^2}{e}\left\{\frac{\partial \mathbf{E}}{\partial t} + (\mathbf{v}\nabla)\mathbf{E} + \left[\frac{\mathbf{v}}{c}\,\frac{\partial \mathbf{H}}{\partial t}\right] + \left[\frac{\mathbf{v}}{c},\,(\mathbf{v}\nabla)\mathbf{H}\right]\right\}. \tag{8*}$$

The equation (7) differs from those usual in mechanics, by being non-lagrangian, i.e. it cannot be obtained by varying a Lagrangian. This already implies that, at least in the usual acceptance, there are no conservation laws in this model. One can convince oneself explicitly of the nonconservation of energy. Indeed, the work of the force (8) is

$$A = \frac{dT}{dt} = \mp \frac{mcl_0^2}{e}\left\{\mathbf{v}\frac{\partial \mathbf{E}}{\partial t} + (\mathbf{v}\nabla)(\mathbf{E}\mathbf{v})\right\}, \tag{9}$$

where T is the kinetic energy of the body. For the nonconservation of energy the important term is the second term in Eq. (9). The first term in (8) or in (9) has actually a potential character, and can therefore not lead to energy nonconservation. Even simpler: the first term in (8) can be obtained from the Lagrangian $\pm mcl_0 \mathbf{v}\mathbf{E}/e$. It is impossible to find an appropriate Lagrangian for the second term, it has an explicitly non-potential form, and leads to energy nonconservation, as we shall show below in simple examples.

Thus, the term which is most important for us has the form

$$A_{\text{r}} = \mp \frac{mcl_0^2}{e} v_i v_j \frac{\partial E_i}{\partial x^j}, \quad i,j = 1,2,3. \tag{10}$$

For the purpose of illustration, let us first consider the simplest example. Assume that a body of mass M rotates with angular velocity ω at a distance R around the charge Q. Then the rate of change of the energy, $d\mathscr{E}/dt$ is

$$\frac{d\mathscr{E}}{dt} = \mp \frac{Mcl_0^2 Q\omega^2}{eR}. \tag{11}$$

A second example which we consider here is a classical ideal gas of equally charged particles (the charge is ξe, where $\xi = \pm 1$). In this case the change of energy of each individual particle is given by Eq. (10), which leads to the following value for the unit volume of the gas:

$$\frac{d\mathscr{E}}{dt} = \mp \frac{mcl_0^2}{e}\int v_i v_j \frac{\partial E_i}{\partial x^j}\rho(v^2)\,d^3v, \tag{12}$$

where $\rho(v^2)$ is the Maxwell velocity distribution

$$\rho(v^2) = n(m/2\pi kT)^{3/2}\exp(-mv^2/2kT), \tag{13}$$

(n, T are respectively the density and temperature of the gas). Integrating in (12), we obtain

$$\int v_i v_j \frac{\partial E_i}{\partial x^j}\rho(v^2)\,d^3v = \frac{kT}{m} n \,\text{div}\,\mathbf{E}. \tag{14}$$

* $\left[\frac{\mathbf{v}}{c}\frac{\partial \mathbf{H}}{\partial t}\right] \equiv \frac{\mathbf{v}}{c} \times \frac{\partial \mathbf{H}}{\partial t}$.

Substituting (14) into (12) and remembering that div E $= 4\pi\rho = 4\pi\xi en$ we obtain

$$\frac{d\mathscr{E}}{dt} = \mp \xi 4\pi c l_0^2 n^2 kT. \tag{15}$$

We thus find that a gas consisting of equally charged particles either heats up or cools down by itself. Thus, if the upper sign holds in (10) the gas will heat up. In nature one does not find a gas made up of particles of one sign of charge only, since it is explicitly unstable. If we consider a gas containing an equal number of positive and negative particles, i.e., a neutral plasma, the effect (15) disappears, at least to first order in l_0^2, since the mean charge density vanishes. We consider this effect in more detail in the next section, and show that in the next order in l_0^2 an effect appears nevertheless.

3. ENERGY PRODUCTION IN A HOT NEUTRAL PLASMA

Consider a fully ionized plasma consisting of electrons and protons with equal average density n, at a temperature T. As an example, take the Sun where $n \approx 10^{24}\ \mathrm{cm}^{-3}$, the average temperature is $10^{7\circ}$K. It is easy to see that under such conditions the plasma is fully ionized, and let us furthermore assume that a classical description is acceptable. Consider first the change in energy of the electronic and ionic components separately. For the electrons, we obtain as in the preceding section

$$\frac{d\mathscr{E}_e}{dt} = \mp 4\pi c l_0^2 kT_e n_e \left(n_p - n_e + \frac{1}{\Delta V}\right), \tag{16}$$

where T_e is the electron temperature. The last factor in (16) requires some explanations. It determines the charge density $\rho = e(n_p - n_e + 1/\Delta V)$. Here we have chosen a volume ΔV where the electron and proton densities can differ from the mean density, and the last term appears due to the fact that each electron is in the field of all the protons inside that volume, as well as in the field of all the electrons except itself.

It is necessary to perform an averaging in the expression (16), namely,

$$\overline{n_e / \Delta V} = n / \Delta V; \quad \overline{n_e(n_p - n_e)} = \overline{\Delta n_e(\Delta n_p - \Delta n_e)} = -\xi_e.$$

Thus, in place of (16) we obtain

$$\frac{d\mathscr{E}_e}{dt} = \mp 4\pi c l_0^2 kT_e n \left(\frac{1}{\Delta V} - \frac{\xi_e}{n}\right). \tag{17}$$

We shall return below to the choice of the volume ΔV, and now we write the expression for the corresponding rate of change of the energy of the protons (T_p is the protonic temperature)

$$\frac{d\mathscr{E}_p}{dt} = \pm 4\pi c l_0^2 kT_p n \left(\frac{1}{\Delta V} - \frac{\xi_p}{n}\right). \tag{18}$$

If the electron and proton temperatures are identical, the corresponding fluctuations are also equal, $\xi_e = \xi_p$, and consequently the um of (17) and (18) yields zero, i.e., the total energy remains unchanged. At a first glance the equality of the temperatures seems compulsory, since we assume thermal equilibrium in the system. However, if we turn again to a comparison of Eqs. (17) and (18) we see that owing to the different signs in these expressions the temperature of one of the components increases, and that of the other, decreases. Of course, the electron-proton collisions will tend to equalize the temperatures, and as a result of this an equilibrium temperature difference will establish itself, difference which can be determined from a known expression from plasma kinetic theory (cf., e.g., the book by Shkarofsky et al.,[12], p. 239)

$$\frac{\partial T_e}{\partial t} = -\frac{32\pi^{1/2} n e^4 (T_e - T_p)\ln\Lambda}{3mM(2kT_p/M + 2kT_e/m)^{3/2}}, \tag{19}$$

where $\Lambda = m^{1/2}kT/(6\pi n)^{1/2}e\hbar$ and m and M are respectively the electron and proton masses. It follows from (17)

$$T_e - T_p = \mp \frac{c l_0^2 TM(2\pi kT)^{3/2}}{4\pi n e^4 m^{1/2}\ln\Lambda}\left(\frac{1}{\Delta V} - \frac{\xi}{n}\right). \tag{20}$$

In this formula the temperature difference has been neglected in the right-hand side, since this leads to higher-order corrections.

We can now use the expression (20) to estimate the changes in energy. In order to simplify the expressions we assume that the fluctuations of the electron and proton densities are equal[3]: $\xi_e = \xi_p$. Thus we obtain from (17), (18) and (20)

$$\frac{d\mathscr{E}}{dt} = \frac{d}{dt}(\mathscr{E}_e + \mathscr{E}_p) = \mp 4\pi c l_0^2 kn\left(\frac{1}{\Delta V} - \frac{\xi}{n}\right)(T_e - T_p)$$
$$= \frac{(2\pi)^{3/2}(c l_0^2)^2 M(kT)^{5/2}}{e^4 m^{1/2}\ln\Lambda}\left(\frac{1}{\Delta V} - \frac{\xi}{n}\right)^2. \tag{21}$$

Thus, independently of the sign in the fundamental equation, there will be energy production in a neutral plasma. The energy increase per unit time and unit volume is given by Eq. (21). However, there is still an indeterminacy in this formula, related to the choice of the volume element ΔV. The simplest considerations lead to the following determination of this volume element in terms of the Debye radius[4]

$$r_D = (kT / 4\pi n e^2)^{1/2}.$$

Indeed, if one considers a small spherical volume of radius r, it is known that as long as $r \ll r_D$ the fluctuations are determined by the usual statistical expression $\xi = n/\Delta V$. For $r > r_D$ the screening suppresses the fluctuations by a factor of $(r_D/r)^2$. Based on these considerations, we select the following expression for the density fluctuations:

$$\xi = \begin{cases} n/\Delta V, & r < r_D, \\ (n/\Delta V)(r_D/r)^2, & r > r_D. \end{cases} \tag{22}$$

Then the expression entering (21) has the form

$$\frac{1}{\Delta V} - \frac{\xi}{n} = \begin{cases} 0, & r < r_D, \\ \dfrac{3}{4\pi r^3}\left(1 - \left(\dfrac{r_D}{r}\right)^2\right), & r > r_D. \end{cases} \tag{23}$$

The function (23) has a maximum at $r = (5/3)r_D$ and it is natural to select just this value, since it yields the largest energy production. Then (21) gets replaced by

$$\frac{d\mathscr{E}}{dt} = \frac{243\sqrt{2}(c l_0^2)^2 M(kT)^{5/2}}{6250\pi^{1/2}e^4 r_D^6 m^{1/2}}\ln^{-1}\left[\frac{m^{1/2}kT}{(6\pi n)^{1/2}e\hbar}\right]. \tag{24}$$

It should be remarked that the numerical coefficient

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[3]In view of the temperature difference, this is not exactly so, however, taking into account the inequality of the fluctuations does not change the result significantly.

[4]This is valid as long as r_D does not become smaller than the Bohr radius.

in Eq. (24) is not exact. Thus, smoothing the approximation (22) for the fluctuations leads to a change of this coefficient. We have already remarked that taking into account the difference in fluctuations of the proton and electron densities will also affect the magnitude of the coefficient. Therefore the expression (24) should be considered as an estimate of the order of magnitude of the effect.

The expression (24) contains a relatively strong dependence on the density $\sim n^2$. However, for very large densities, when r_D becomes smaller than the Bohr radius r_B, the density-dependence disappears, and r_B enters the formula effectively in place of r_D. Therefore for stars, i.e. for plasma formations with a mass of the order of a solar mass and temperature 10^7-10^9 °K, a maximal effect is obtained for $n \approx 10^{25}-10^{26}$. Choosing the Sun as an example, we obtain the following limitation on the length l_0

$$l_0 \leqslant 0.5 \cdot 10^{-17} \text{ cm} \tag{25}$$

This estimate does not contradict the value (5), which is necessary in order to explain CP-violation in the weak-electromagnetic model, but is so close to it that energy nonconservation effects in the Sun could manifest themselves. It is the place here to call attention to the indications that there seems to be a contradiction in the energy balance of the Sun related to the rather low neutrino luminosity of this star[13]. The mechanism under consideration can also be used in order to explain the anomalously large luminosities of Jupiter and Saturn, which according to the measurements[14] emit 2.5 times more energy than they receive from the Sun. It does not seem particularly meaningful to apply the expression (24) to quasars and galactic nuclei, where there are also difficulties with the explanation of the energy balance (cf. e.g.,[15,16]) (moreover (24) yields a small effect in this case), since nonstationary processes play, possibly, an important role in these objects, and we have not taken into account such processes. In one way or another, the astrophysical data so far do not contradict the model under discussion for a length l_0 of the order (5), (25).

4. SOME POSSIBILITIES FOR EXPERIMENTAL VERIFICATION

The effects in a neutral plasma which we discussed in the preceding section are probably unobservable under laboratory conditions, in view of their smallness. Here we list some examples which are possibly more convenient for verification. Let us consider an electron gas without an admixture of positively charged particles. Assume that by means of a method unknown to the author it was possible to localize in a volume the electron gas at equilibrium at a temperature T and density n. Making use of the expression (10) for the increase (or decrease) of the energy of one particle per unit time and of the known equations of the theory of Fermi gases, we find that the change of the energy per unit volume and unit time is given by the following integral

$$\frac{d\mathscr{E}}{dt} = \mp \frac{2mcl_0^2}{h^3 e} \int v_i v_j \frac{\partial E_i}{\partial x^j} d^3p F\{1-F\},$$
$$F = \left[\exp\left(\frac{p^2}{2mkT} - \frac{\zeta}{kT}\right) + 1\right]^{-1}, \tag{26}$$

where ζ is the Fermi limit of the energy. The last bracket requires some explanations. It gives the relative number of unoccupied levels for the appropriate energy. Since, in view of the identity of the electrons and the Pauli principle, transitions are only possible onto unoccupied levels, the presence of this factor is absolutely necessary. Effecting the integration over the angles and an obvious change of variables, we obtain

$$\frac{d\mathscr{E}}{dt} = \mp \frac{8\pi cl_0^2}{3h^3 e} \operatorname{div} \mathbf{E} \int_{-\zeta/kT}^{\infty} \frac{e^x (x + \zeta/kT)^{3/2} dx}{(e^x+1)^2} (2mkT)^{3/2} kT. \tag{27}$$

Noting that div $\mathbf{E} = -4\pi en$, and the relation between the integral and the total particle number

$$(2mkT)^{3/2} \frac{8\pi}{3h^3} \int_{-\zeta/kT} \frac{e^x (x+\zeta/kT)^{3/2} dx}{(e^x+1)^2} = n,$$

we obtain, finally

$$\frac{d\mathscr{E}}{dt} = \pm 4\pi cl_0^2 n^2 kT. \tag{28}$$

We see that the result coincides exactly with the classical case (15). In our view this result is not devoid of interest, and shows that in the estimation of the energy nonconservation one may neglect the quantum corrections, at least in lowest order in l_0^2.[5)]

It is also interesting to follow the change of temperature with time, neglecting the energy losses due to radiation, heat conduction, etc. Making use of known formulas we obtain, for $kT \ll \zeta$

$$\frac{d\mathscr{E}}{dt} = \frac{1}{2}\pi^2 n \frac{k^2 T}{\zeta} \frac{dT}{dt} \qquad \zeta = \frac{h^2}{2m}\left(\frac{3n}{8\pi}\right)^{2/3}. \tag{29}$$

It follows from (29) and (28) that

$$T = T_0 \pm 8cl_0^2 n\zeta t / \pi k. \tag{30}$$

Thus, the characteristic time, over which there occurs a significant change in temperature, is

$$\tau = \pi k T_0 / 8cl_0^2 n\zeta. \tag{31}$$

In order to estimate the magnitude of this time we select a large density, $n = 10^{23}$ cm^{-1}, of the order of the electron density in a metal, and the temperature $T_0 = 10^3$ °K; for l_0 we pick the value (25). Then

$$\tau = 5.6 \cdot 10^{-2} \text{ sec}.$$

For smaller densities this time is, of course, larger. In one way or another, if one succeeds experimentally to create a sufficiently dense electron gas, the effects predicted here are susceptible to verification.

One can consider yet another example. Imagine a body, e.g., a hollow metallic sphere of radius R, in equilibrium with black-body radiation at temperature T_0.[6)] Placing a charge Q on the sphere will produce a nonzero charge distribution, and owing to energy nonconservation the temperature of the body will change according to the equation

$$4\pi R^2 \Delta 3nk \frac{dT}{dt} = \mp 4\pi cl_0^2 \frac{Q}{e} 2nkT + \frac{\pi^2 k^4 R^2}{15\hbar^3 c^2}(T_0^4 - T^4). \tag{32}$$

After some time the system attains an equilibrium state ($dT/dt = 0$), with the temperature differing from T_0. For $\Delta T = T - T_0$, assuming $\Delta T \ll T_0$, we obtain

5)This circumstance was considered in the astrophysical estimates.

6)E.g., the sphere is placed in a thermostat, and one may neglect heat conduction and other losses.

$$\frac{\Delta T}{T_0}=\mp\frac{30l_0^2n}{\pi e}\left(\frac{\hbar c}{k}\right)^3\frac{Q}{R^2T_0^3}=\mp 0{,}6\cdot 10^{-3}\frac{Q}{R^2T_0^3}. \qquad (33)$$

Here we have assumed $n = 10^{23}$. Noting that Q/R^2 is the field strength E of the electric field at the surface of the sphere, and choosing for example $E = 10^3$ e.s.u. (i.e., 3×10^5 V/cm), we obtain that for a temperature of several degrees, the temperature difference may be significant. One should note the time over which equilibrium establishes itself. It follows from (33) that the characteristic time is

$$\tau = 3eR^2\Delta / 2cl_0^2Q. \qquad (34)$$

Thus, the experimental verification of the proposed scheme seems possible, although the corresponding experiments are relatively difficult and delicate.

5. CONCLUSION

The meaning of the reasonings which have led us to the hypothesis of energy nonconservation consists in a connection between time-irreversibility (violation of T-invariance) and noninvariance with respect to time-translations (nonconservation of energy). To clarify whether this is indeed so seems a very important problem, and therefore the corresponding experiments, including the astrophysical ones, are rather desirable.

One should remark that an application of this scheme to essentially quantum systems (nuclei, atoms) is so far impossible, since we do not know how to quantize nonlagrangian equations.

Finally, as a last remark, we also note that this model leads to momentum nonconservation. We will, perhaps, discuss some effects related to this in the future.

The author is sincerely grateful to N. N. Bogolyubov, S. N. Vernov, S. S. Gershteĭn, A. A. Logunov, B. M. Pontecorvo, A. N. Tavkhelidze, V. V. Usov, A. T. Fillipov and O. A. Khrustalev for numerous fruitful discussions.

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Translated by M. E. Mayer
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