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ON THE PRINCIPLE OF RELATIVITY AND ITS VIOLATION IN THE PHENOMENA OF SPIN PRECESSION OF MOVING CHARGED PARTICLES

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It is indeed a matter of great difficulty to discover, and effectually to distinguish, the True motions of particular bodies from the Apparent: because the parts of that immoveable space in which those motions are performed, do by no means come under the observations of our senses. Yet the thing is not altogether desperate; for we have some arguments to guide us, partly from the apparent motions, which are the differences of the true motions; partly from the forces, which are the causes and effects of the true motions.

Isaak Newton

INTRODUCTION

The below analysis of spin precession of moving charged particles is based on the well-known facts and transformations which are now considered as direct corollaries of special theory of relativity (STR). However, the same transformations strictly follow from Lorentz's "ether" theory which involves metric axioms of new mechanics corresponding to real space with the finite speed of propagation of any signals and interactions. Being only a consequence of an event and not a reason for it, the principle of relativity is valid in this theory so far as its validity can be guaranteed by the fundamental laws of the Nature. Lorentz's inductive approach implying a certain material structure of physical vacuum is virtually a basis of a more general physical theory which in its turn is a basis of the field conception (because in any case the field symbols are physically senseless without the material essence of space); within this conception one finds consistent explanations of all corollaries and fundamental postulates of STR and, naturally, will impose limits on the applicability of this method.

Still, this logically flawless approach has a weak spot in the very basis because there is no yet a physical method for separating a privileged coordinate system where the fundamental ideas of the theory are formulated. It is looking for this method that must be the main task of this theory. Until this criterion is not found, the theory seems to run idle, it yields the same results as STR and allows the curious compensatory mechanism of formation of solutions, based immediately on the STR ideas, in a moving system of coordinates to be followed only in details. In view of this Lorentz's conception is believed not to be distinguished from Einstein's one experimentally. It is undoubtedly true only for a class of phenomena satisfying the requirements of the relativity principle, it being evident only within classical mechanics. The absence of consistent relativistic mechanics (except for the problem of motion of a material point in the external field) reduces it to a simple belief based on generalization of limited number of experimental facts. Following the philosophical idea that the Nature is not a thing in itself, one of the conceptions must be experimentally rejected. Then only the discovery of violation of the relativity principle can settle the argument between these two conceptually polar theories. In this connection it should be mentioned that space isotropy of physical processes in moving systems, resulted only from the STR relativity principle, cannot be in principle proved experimentally and, consequently, has to be a hypothesis for ever. Now the fundamental ideas of Lorentz's theory - changes in the physical scale of the moving system due to absolute motion in real space - are not ad hoc hypotheses but objective reality. So, while within STR there is no and cannot be an experiment that refutes Lorentz's theory, within Lorentz's theory an experiment like this is always possible. Evidently, none of the proposed and performed experiments could not solve the problem in principle as yet. Substantiating the experiments, the authors followed either classical mechanics which reflects the properties of the space of unlimited velocities in the form of the metric postulates that are the basis of this mechanics, or the wrong premises leading to wrong conclusions and effects whose absence is equally in favour of each of the approaches discussed.

Now, of course, only the experiment based on the consistent Lorentz conception and not yielding the result predictable within STR can be logically justified.

It is substantiation of this experimentum crucis that is proposed below to a thoughtful reader.

1. SPIN PRECESSION IN THE ELECTROMAGNETIC FIELD

As is known, when a charged particle of mass m and charge e with spin s and gyromagnetic factor g moves, the angular velocity ω_s of precession of spin around the direction of the magnetic field of strength B transverse to the particle velocity vector decreases due to the Thomas precession effect ω_T [1] and takes on the value

$$\omega_s = \omega_L + \omega_T = \frac{g}{2}\cdot\frac{eB}{mc} - \frac{\gamma-1}{\gamma}\cdot\frac{eB}{mc} = \frac{eB}{mc}\left(a + \frac{1}{\gamma} \right) , \qquad (1)$$

where ω_L is the frequency of the Larmor precession, $\gamma=(1-\beta^2)^{-1/2}$ is the Lorentz factor, $a = g/2-1$ is the anomalous part of the particle's g-factor.

It follows from Eq.1 that the spin precession frequency differs from the cyclotron frequency $\omega_c = \frac{eB}{mc\gamma}$ by $\omega_{s-c} = \frac{eB}{mc}a$ which does not depend on the particle velocity. This feature of spin precession was quite effectively used for checking the quantum electrodynamics predictions in the well-known experiments on the precision determination of the anomalous (vacuum) part of the magnetic moment of electrons and muons.

In a more general case of particle movement in a uniform static electromagnetic field the problem was solved by Bargmann, Michel and Telegdi [2]. This paper covers all general cases obtained earlier by different authors. In the case of trachoidal particle movement in crossing transverse fields B, E the above solution allows to describe the angular velocity of spin precession by the equation [2,3,4]

$$\omega_s = \frac{e}{mc}\left\{\left(a + \frac{1}{\gamma} \right) B + \left(\frac{1}{\gamma^2-1} - a - \frac{\gamma}{\gamma^2-1}\right)[\beta\cdot E]\right\} . \qquad (2)$$

This equation was used in setting up the third most precise muon experiment at CERN [4] with the electrostatic focusing of particles moving along the closed trajectory in a uniform magnetic field. If there is a transverse electric field, the expression for the cyclotron frequency has the form

$$\omega_c = \frac{e}{mc}\left(\frac{B}{\gamma} - \frac{\gamma}{\gamma^2-1}[\beta\cdot E]\right) , \qquad (3)$$

where the second term is to take into account the slowing-down effect of the electric field. Following equation (2), the spin precession velocity directly determined in the experiment with regard to the particle momentum is

$$\omega_{s-c} = \omega_s - \omega_c = \frac{e}{mc}\left\{ a\,B + \left(\frac{1}{\gamma^2 - 1} - a \right)[\beta\cdot E] \right\} . \tag{4}$$

If, for example, the particle velocity is chosen such that $\gamma = \sqrt{1+1/a}$, then the dependence of ω_{s-c} on β and E disappears, which was used in practice to obtain the maximum possible precision in determination of the anomalous part of the magnetic moment of the muon.

Now let's come back to the analysis of initial equation (2), writing it in a more compact form:

$$\omega_s = \frac{e}{mc}\left\{ \left(a + \frac{1}{\gamma} \right) B - \left(a + \frac{1}{\gamma + 1} \right)[\beta\cdot E] \right\} . \tag{5}$$

Our task will be to see if it is possible to satisfy the principle of relativity in the phenomena of spin precession of moving particles described by equation (5). We shall assume that

a) equation (5) correctly describes the spin behaviour at least in the coordinate system which is at rest with regard to physical vacuum, changes in its state being the essence of any fields. As follows from equation (5), spin interaction in this system is only determined by the absolute velocity of a particle $\beta = v/c$ and the values of the field component strength along the particle trajectory;

b) if one imparts motion to the field source, this will only result in changes in the field components produced by it in space. Variation of the relative motion between the particle and the field source does not change the character of interaction with the field, and equation (5) remains valid in the rest system of coordinates.

These assumptions allow one to reduce the problem of finding the spin precession velocity measured in the moving reference system connected with the field source to a simple problem of finding new field components of a moving source, recalculation of the precession frequency in the source's own time, and obtaining of the correction for the shift of the simultaneity of the moving reference system.

2. INVARIANT CASES OF SPIN "MOTION"

Let us make sure that within the above assumptions equation (5)

leads to the invariant expression for the spin precession frequency of the particles moving together with the source of the magnetic field. If the field source at rest produces, for example, the magnetic field strength B_o, then, moving at a speed of β in the plane perpendicular to the vector B_o, it produces the strength $B = \gamma B_o$, and the electric field $E = -[\beta B] = -\gamma[\beta B_o]$ transverse to the vectors β and B appears. Substituting these values of the field components into equation (5) and expressing the frequency in the moving system's own time, we obtain a correct expression for the Larmor spin precession which is at rest with regard to the particle field source:

$$\begin{aligned} \omega_s' = \omega_s\,\gamma &= \frac{eB_o\gamma^2}{mc}\left(a + \frac{1}{\gamma} - a\,\beta^2 - \frac{\beta^2}{\gamma+1} \right) = \\ &= \frac{eB_o\gamma^2}{mc}\left(a\,\frac{1}{\gamma^2} + \frac{1}{\gamma} + \frac{1-\gamma}{\gamma^2} \right) = \frac{eB_o}{mc}\,(a + 1) = \frac{g}{2}\cdot\frac{eB_o}{mc} . \end{aligned} \tag{6}$$

Equation (5) yields the same value if we apply it to a particle and a magnetic field source, both at rest. So, the spin precession frequency measured on the scale of the source's own time does not depend on the source movement in space together with the particle, which agrees with the principle of relativity required in this problem.

Now let us find the dependence of spin precession on the particle velocity β when the particle moves along the linear path in the field of a fixed and then moving source. In this case one must evidently apply an electric field $E_o = -[\beta B_o]$ transverse to the vectors β and B_o to neutralize the deviating effect of the field B_o (the limiting case of the trachoidal movement). Substituting these values of the field components into formula (5) we obtain the following result:

$$\omega_{s_1} = \frac{eB_o}{mc}\left\{ a + \frac{1}{\gamma} - \left(a + \frac{1}{\gamma + 1} \right) \beta^2 \right\} = \frac{g}{2}\cdot\frac{eB_o}{mc\gamma^2} . \tag{7}$$

Let the same combined source that produces the fields B_o and E_o at rest now move in the opposite direction , and the particle is immobile in space. In this case the components of the resulting field affecting the immobile particle are evidently

$$B = B_o/\gamma \quad \text{and} \quad E = 0 .$$

(The external electric field is completely neutralized by the electric field of the opposite sign of the moving magnet.) Substituting these values of the field components into equation (5) and expressing the precession frequency in terms of the source's own time scale, we obtain another result:

$$\omega'_{s_2} = \omega_{s_2}\gamma = \frac{eB}{mc}\,(\,a + 1\,)\,\gamma = \frac{g}{2}\cdot\frac{eB_o}{mc}\;. \tag{8}$$

The γ^2-fold difference in spin precession in these opposite cases indistinguishable from the point of view of the principle of relativity does not contradict this principle, because in the latter case the precession frequency will differ from the calculated one owing to the changes in precession measurement conditions. It can be exemplified by the observation method based on the monitoring of the spin flip angle at a finite time of observation. Indeed, in this experiment one must use the fixed base of flight L_o, and the Lorentz change in its length in the case of a moving source results in full compensation for the difference in frequencies

$$\varphi_1 = \omega_{s_1}\Delta t_1 = \omega_{s_1}\frac{L_o}{c\beta} = \frac{g}{2}\cdot\frac{eB_oL_o}{mc^2\beta\gamma^2}$$

$$\varphi_2 = \omega_{s_2}\Delta t_2 = \omega_{s_2}\frac{L_o}{c\beta\gamma} = \frac{g}{2}\cdot\frac{eB_oL_o}{mc^2\beta\gamma^2}\;.$$

Yet, if the radio-frequency observation method with an additional radio-frequency field is used, the length of the flight base is of little importance. Quantum transitions take place only if the spin precession frequency and the r.f. field frequency coincide, and the effect would seem to be observable. However, in this case there is also an evident effect of compensation for the frequency difference owing to r.f. field phase gradient directed along the source movement (in the case of a moving source), it is related to the source simultaneity and causes a precisely γ^2-fold increase in the effective frequency acting on the particle ($\nu_{ef}=\nu_o\gamma^2$)* and, consequently, a decrease in the observed resonant frequency of the quantum transitions to the value corresponding to the case of an immobile source.

Now let's analyze spin precession in more general cases when the absolute particle velocity β differs from the source velocity β_o in value, remaining parallel to the vector β_o.

If $\beta_\wedge$ is a velocity measured in the reference system of the mo-

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*) Derivation of the generalized expression for ν_{ef} is at page 11.

ving source, then, because of difference in time, length and simultaneity scales, the value of β has a simple relativistic relation to β_o and $\beta_\wedge$:

$$\beta_1 = \frac{\beta_o + \beta_\wedge}{1 + \beta_o\beta_\wedge} \qquad\qquad \beta_2 = \frac{\beta_o - \beta_\wedge}{1 - \beta_o\beta_\wedge}.$$

The additional transverse electric field, which is necessary for retaining the linear path of particles, must evidently satisfy the condition $E_o=-[\beta_\wedge B_o]$. In this case the new values of the field components of the moving source will be

$$B = \gamma_o B_o(\,1 + \beta_o\beta_\wedge) \quad и \quad E = -\,\gamma_o[(\,\beta_o + \beta_\wedge)B_o]\;\;,$$

where $\gamma_o = 1/\sqrt{1-\beta_o^2}$. Substituting these values and the values of the Lorentz factors of the particle

$$\gamma_{1,2} = 1/\sqrt{1-\beta_{1,2}^2}\;\;,$$

into (5) and doing algebraical transformations, we obtain a simple form of (5)

$$\omega'_{s_1} = \omega_{s_1}\gamma_o = \frac{g}{2}\,\frac{eB_o(1-\beta_\wedge^2)}{mc(1+\beta_\wedge\beta_o)}$$

for particle movement in the direction of the field source movement, and

$$\omega'_{s_2} = \omega_{s_2}\gamma_o = \frac{g}{2}\,\frac{eB_o(1-\beta_\wedge^2)}{mc(1-\beta_\wedge\beta_o)}$$

for movement in the opposite direction. Solutions of the previous problem are naturally specific cases of this general solution for $\beta_o=0$ (immobile source) and $\beta_o=|\beta_\wedge|$ (immobile particle $\beta_2=0$).

This general solution, like the previous specific one, also yields the invariant value of the spin flip angle, which follows from the comparison of times of flight of the particle over the moving base L_o

$$\frac{\Delta t_1}{\Delta t_2} = \frac{L_o\sqrt{1-\beta_o^2}}{c(\beta_1 - \beta_o)} \Big/ \frac{L_o\sqrt{1-\beta_o^2}}{c(\beta_2 - \beta_o)} = \frac{1 + \beta_o\beta_\wedge}{1 - \beta_o\beta_\wedge}$$

consequently, $\varphi_1 = \omega_{s_1}\Delta t_1 = \varphi_2 = \omega_{s_2}\Delta t_2$. A similar compensation will evidently take place at the radio-frequency method of observation as well, since the effective frequency of the variable field acting on the particle changes with the sign reverse of the particle velocity against the moving field source. There is no an effect like this only in the case of a field source at rest. In this case the variable field frequency coincides with the effective frequency acting on a particle moving in the field.

3. NON-INVARIANT SPIN PRECESSION

Now, using the above technique of precession calculation in a moving reference system, whose correctness was shown by consideration of simple cases of spin movement, we turn to description of the movement leading to the evident violation of the relativity principle. For this purpose it is enough to switch off the additional electric field E_o, which removes the particle path bending, in the last of the problems considered. It is equivalent to taking into account the Thomas precession, except for the case considered in the first problem, when the particle velocity β is equal to the source velocity β_o.

So, let us come back to the case when the components of the field of a moving source are

$$B = B_o \gamma_o \quad \text{and} \quad E = - \gamma_o [\beta_o \cdot B_o] \quad ,$$

where β_o is the field source velocity, but the velocities of the particles in space differ from the source velocity. In sufficiently small sections of the trachoidal path, where a tangent is parallel to the source velocity β_o, the relation between vectors $\beta_{1,2}$, $\beta_\wedge$ and β_o is evidently of the same simple form as in the previous problem:

$$\beta_1 = \frac{\beta_o + \beta_\wedge}{1 + \beta_o\beta_\wedge} \quad , \qquad \beta_2 = \frac{\beta_o - \beta_\wedge}{1 - \beta_o\beta_\wedge} \quad .$$

Substituting new values of the field components and those of $\beta_{1,2}$ particle velocity into eq.(5) we obtain

$$\omega'_{s_1} = \omega_{s_1}\gamma_o = \frac{eB_o\gamma_o^2}{mc}\left[a\left(1-\beta_o\beta_1\right) + \frac{1}{\gamma_1} - \frac{\beta_o\beta_1}{\gamma_1+1}\right],$$
$$\omega'_{s_2} = \omega_{s_2}\gamma_o = \frac{eB_o\gamma_o^2}{mc}\left[a\left(1-\beta_o\beta_2\right) + \frac{1}{\gamma_2} - \frac{\beta_o\beta_2}{\gamma_2+1}\right] \qquad (9)$$

Substituting the relevant values of β_1, β_2, γ_1, γ_2 and doing algebrai-

cal transformations, we obtain the following final expressions for the spin precession frequencies on the time scale of the moving field source:

$$\omega'_{s_1} = \frac{eB_o}{mc}\left(a + \frac{1}{\gamma_\wedge}\cdot\frac{\gamma_o + \gamma_\wedge}{1 + \gamma_o\gamma_\wedge(1 + \beta_o\beta_\wedge)}\right)\cdot\frac{1}{1 + \beta_o\beta_\wedge} \quad ,$$
$$\omega'_{s_2} = \frac{eB_o}{mc}\left(a + \frac{1}{\gamma_\wedge}\cdot\frac{\gamma_o + \gamma_\wedge}{1 + \gamma_o\gamma_\wedge(1 - \beta_o\beta_\wedge)}\right)\cdot\frac{1}{1 - \beta_o\beta_\wedge} \quad , \qquad (10)$$

where $\gamma_\wedge = 1/\sqrt{1-\beta_\wedge^2}$. These expressions yield only the extremum values of spin precession corresponding to the extremum values of the particle velocity in space. In other sections of the particle path the frequencies will evidently have intermediate values blending into one at the points where the particle velocity vector in the source frame is perpendicular to the source velocity vector. In this specific case the relation between the velocities β, β_o and $\beta_\wedge$ is expressed by the formula

$$\beta = \sqrt{\beta_o^2 + \beta_\wedge^2(1-\beta_o^2)} \quad ,$$

and vector β makes an angle α with the direction of field E; the angle α is determined by the relation

$$\sin\alpha = \beta_o \,/\, \beta \quad .$$

Substituting these values of β and $\sin\alpha$ into (5), we obtain the precession frequency values in the directions of the particle motion along the circular path which is closed in the close frame and perpendicular to vector:

$$\omega'_s = \omega_s\,\gamma_o = \frac{e\gamma_o}{mc}\left[\left(a + \frac{1}{\gamma}\right)B_o\gamma_o - \left(a + \frac{1}{\gamma+1}\right)\beta\gamma\sin\alpha\; B_o\gamma_o\beta_o\right] =$$
$$= \frac{eB_o}{mc}\left(a + \frac{1}{\gamma_\wedge}\cdot\frac{\gamma_o + \gamma_\wedge}{1 + \gamma_o\gamma_\wedge}\right) \quad . \qquad (11)$$

As it follows from the previous problem, the conditions for observation of the effect in moving source frame can cancel only the common factors $(1+\beta_o\beta_\wedge)$ and $(1-\beta_o\beta_\wedge)$ in expression (10); consequently, the precession frequencies detected in the source's own frame turn out to be complex functions of β_o - the field source velocity in space. Only at β_o=0 formulae (10) and (11) lead to an ordinary expression for spin precession of a particle moving in the magnetic field

$$\omega_s' = \frac{eB_o}{mc}\left(a + \frac{1}{\gamma} \right),$$

and at $\beta_\wedge = 0$ it leads to the case of the conventional Larmor precession obtained in the first problem

$$\omega_s' = \frac{g}{2}\cdot\frac{eB_o}{mc}.$$

Now a natural question arises: how could it happen that the initial equation of "spin motion" obtained in a seemingly relativistic-invariant approach contains not only invariant solutions but also a solution which contradicts the relativity principle, and at the same time it allowed one to determine the anomalous part of the magnetic moment of the relativistic muon with an accuracy of 10^{-9} of the full moment of the particle?

At first it should be mentioned that the above-considered invariant problems correspond only to the cases where movement lacks periodicity in the whole variation range of variables, and the wave package mean particles coincided with the mean values in any section of the path. Now let us show that the precession velocity measured in a moving reference frame and averaged over the precession variation period satisfies the principle of relativity. For this purpose we shall first find the dependence of the precession velocity on the value and direction of the particle velocity at an arbitrary point of its path.

The required general solution can be easily found if one uses the expression for adding the velocities β_o and $\beta_\wedge$, which is valid in a general case

$$\beta = \frac{\sqrt{\beta_\wedge^2 + \beta_o^2 + 2\,\beta_\wedge\,\beta_o\cos\theta - \beta^2_\wedge\beta^2_o\sin^2\theta}}{1 + \beta_\wedge\,\beta_o\,\cos\theta},$$

where θ is the angle between the vectors added in the moving frame. In this case the angle θ' between the vectors β and β_o in a rest frame is related to the angle θ as

$$\cos\theta' = \frac{\beta_\wedge\cos\theta + \beta_o}{\sqrt{\beta_\wedge^2+\beta_o^2+2\beta_\wedge\beta_o\cos\theta-\beta_\wedge^2\,\beta_o^2\sin^2\theta}}.$$

Under the conditions of the problem, vector E is always perpendicular to velocity vector β_o. So angle α between vectors E and β is related to angle θ' as $\sin\alpha = \cos\theta'$, and, consequently, the vector product $[\beta E]$ in (5) is reduced to a simple expression

$$[\beta\ E] = \frac{(\beta_\wedge\cos\theta + \beta_o)\beta_o\gamma_o B_o}{1 + \beta_\wedge\beta_o\cos\theta}.$$

As a result, the initial equation (5) gets the form

$$\omega_s' = \frac{eB_o\gamma_o^2}{mc}\left\{a + \frac{1}{\gamma} - \left(a + \frac{1}{\gamma+1}\right)\cdot\frac{(\beta_\wedge\cos\theta + \beta_o)\beta_o}{1 + \beta_\wedge\beta_o\cos\theta}\right\},$$

where $\gamma = (1+\beta_\wedge\beta_o\cos\theta)\gamma_o\gamma_\wedge$, and after substituting γ it is reduced to

$$\omega_s' = \frac{eB_o}{mc(1+\beta_\wedge\beta_o\cos\theta)}\left[a + \frac{1}{\gamma_\wedge}\cdot\frac{\gamma_\wedge + \gamma_o}{1+\gamma_\wedge\gamma_o(1+\beta_\wedge\beta_o\cos\theta)}\right], \qquad (12)$$

whose specific cases are earlier obtained expressions (10) and (11), when θ is equal to zero or $\pi/2$, respectively.

Now let us find a general expression for the effective frequency which acts on the particle in the field of a moving resonator and depends on the simultaneity shift at its ends equal to

$$\Delta t = -\frac{L_o\beta_o\cos\theta}{c\sqrt{1-\beta_o^2}} = \frac{\Delta\tau}{\sqrt{1-\beta_o^2}},$$

here L_o is the resonator length, $\Delta\tau$ is the simultaneity shift in the resonator's own time in the direction of its movement. Evidently, the "increment" of the oscillation number over the length L_o at the frequency ν_o is

$$\Delta N = \nu_o\Delta\tau = \nu\ \Delta t = -\frac{\nu_o L_o\beta_o\cos\theta}{c}.$$

The desired correction is determined by the projection of relative particle velocity on the resonator movement direction

$$\beta_{rel} = \beta_\gamma\cos\theta' - \beta_o \approx \frac{\beta_\wedge\cos\theta\,(1-\beta_o^2)}{1 + \beta_\wedge\beta_o\cos\theta}$$

and the value of the resonator length projection on this direction. So,

$$\nu_{ef} = \nu_o\sqrt{1-\beta_o^2} + \frac{\beta_{rel}\,c\,\Delta N}{L_o\cos\theta\sqrt{1-\beta_o^2}} = \nu_o\sqrt{1-\beta_o^2}\cdot\frac{1}{1 + \beta_\wedge\beta_o\cos\theta}$$

and, consequently, the effective frequency in the moving resonator's own time acting on the particle is

$$\nu_{ef} = \nu_o \frac{1}{1 + \beta_\wedge \beta_o \cos\theta} .$$

So the common factor $1/(1+\beta_\wedge\beta_o\cos\theta)$ for ω'_s in (12) is neutralized during the measurement of the precession frequency in a moving reference frame, and the actually measured local spin precession velocity as a function of the observation angle will have the form

$$\omega''_s = \omega'_s \frac{\nu_o}{\nu_{ef}} = \frac{eB_o}{mc}\left[a + \frac{1}{\gamma_\wedge}\cdot\frac{\gamma_\wedge + \gamma_o}{1+\gamma_\wedge\gamma_o(1 + \beta_\wedge\beta_o\cos\theta)}\right] . \qquad (13)$$

To find the desired mean value $\overline{\omega''_s}$ per total period of precession variation, it is enough to calculate the integral

$$\overline{\omega''_s} = \frac{eB_o}{\pi mc}\int_0^\pi \omega''_s \, d\theta = \frac{eB_o}{mc} a + \frac{eB_o(\gamma_o+\gamma_\wedge)}{\pi mc\gamma_\wedge}\int_0^\pi \frac{d\theta}{1+\gamma_\wedge\gamma_o(1 + \beta_\wedge\beta_o\cos\theta)} .$$

Since

$$\int \frac{dx}{b+c\cdot\cos x} = \frac{2}{\sqrt{b^2-c^2}} \operatorname{arctg}\left[\sqrt{\frac{b-c}{b+c}}\ \operatorname{tg}x\right] \qquad \text{at} \quad b^2>c^2,$$

the searched-for integral A is

$$A = \frac{\pi}{\sqrt{b^2-c^2}} = \frac{\pi}{\sqrt{(1+\gamma_\wedge\gamma_o)^2 - \gamma_\wedge^2\gamma_o^2\beta_o^2\beta_\wedge^2}} = \frac{\pi}{\gamma_o+\gamma_\wedge}$$

So, the average precession frequency in a moving reference frame is really described by the invariant expression

$$\overline{\omega''_s} = \frac{eB_o}{mc}\cdot\left(a + \frac{1}{\gamma_\wedge}\right) .$$

Thus, the above results do not contradict the precision measurements of the average spin precession velocity carried out at high particle energies in order to find the value of the anomalous magnetic moment of muons, and the experimental results do not contain a correction associated with the translational motion of the Earth.

In conclusion we shall show that the reason for the local violation of the relativity principle is the Thomas precession. To do this, we shall analyze an expression for spin precession of the form

$$\omega_{s-T} = \frac{g}{2}\cdot\frac{e}{mc}\cdot(B - [\beta E]) , \qquad (14)$$

which does not contain the correction for the Thomas precession

$$\omega_T = -\frac{e}{mc}\cdot\left(\frac{\gamma-1}{\gamma} B - \frac{\gamma}{\gamma+1} [\beta E]\right),$$

and make sure that it leads to an invariant expression for the local velocity of spin precession in a moving reference system not only for the linear path of the particle but also for the closed one. Actually, substituting the values of the field components from the previous problem $B=\gamma_o B_o$ and $E=-\gamma_o[\beta_o B_o]$ and the value $\beta=\frac{\beta_o+\beta_\wedge}{1+\beta_o\beta_\wedge}$, we obtain

$$\omega'_{s-T} = \omega_{s-T}\cdot\gamma_o = \frac{g}{2}\cdot\frac{eB_o\gamma_o^2}{mc}\left(1-\frac{\beta_o(\beta_o+\beta_\wedge)}{1+\beta_o\beta_\wedge}\right) = \frac{g}{2}\cdot\frac{eB_o}{mc(1+\beta_o\beta_\wedge)} .$$

Consequently, the local spin precession velocity measured in the reference frame of a moving field source with allowance for the effective frequency acting on the moving particle would be

$$\omega''_{s-T} = \frac{g}{2}\cdot\frac{eB_o}{mc} ,$$

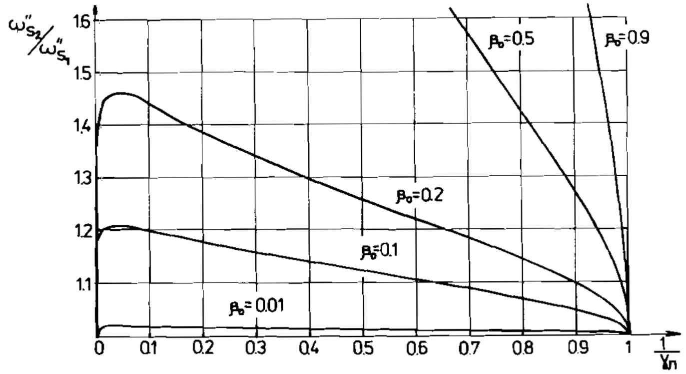
and in this case the measured local frequency would be really independent of the reference frame motion.

It should be mentioned that there is no other form of the expression for spin precession leading to invariant solutions in a moving reference frame. However, form (14) contradicts the experiment at high particle energies and does not represent the reality. The only form of the spin "motion" equation satisfying the relativity principle in the case of a longitudinal magnetic field is

$$\omega_s = \frac{g}{2}\cdot\frac{eB}{mc\gamma} ,$$

which immediately follows from the Lorentz slow-down of time and invariance of longitudinal field components. In all intermediate cases, when $[\beta B] \neq 0$, the Thomas precession manifest itself to this of that extent, and the invariance of the local spin precession velocity is inevitably broken.

To illustrate the relative magnitude of the violation of the relativity principle as a function of the particle velocity $\beta_\wedge$, as it follows from Eq.(13), the Figure shows the dependence of the directly measured frequency ratio $\omega''_{s_2} / \omega''_{s_1}$ at $\theta_2 = \pi$ and $\theta_1 = 0$ on the parameter $\gamma_\wedge$ for electrons at different values of the absolute velocity of the reference frame β_o. It follows from the given calculations that the magnitude of the effect increases almost linearly with the laboratory velocity of a particle achieving the maximum at $\beta_\wedge$ close to one and then decreases tending to one because of the increasing invariant contribution due to the anomalous part of the magnetic moment of the particle. The effect also increases almost linearly with the velocity of



the laboratory in space. In the case of transverse movement, as follows from (13), the relativity principle is also violated but it is the second-order violation with respect to parameter β_o.

CONCLUSION

Thus, the analysis of the spin precession phenomenon described by equation (5) allows the conclusion that in this process the relativity principle is heavily violated to the first order with respect to v/c and, consequently, it is hardly possible in principle to determine its absolute velocity and the direction of its motion in space by means of the experiments on the Earth. As can be easily shown, it was impossible in all the relevant experiments because of the Lorentz variation of the physical scale (length, time and mass units) of the moving reference frame. However, the spin precession phenomenon belongs to the motion class for which the Lorentz transformation of the physical

scale is not the sufficient condition for obtaining the invariant solution in a moving reference frame. As follows from the given analysis, the direct reason for violation of the relativity principle is the existence of the Thomas precession $\omega_T = (\gamma - 1)v/R$ related to the absolute curvature of the particle trajectory in space $k = 1/R$, determined by the real field components and the absolute particle velocity v. As a result, two extreme situations, e.g. with the relativistic particle moving in the field of an immobile magnet, or with the relativistic magnet incident on an immobile particle, are completely different despite the full similarity of particle trajectories. Indeed, in the former case there is the Thomas precession which leads to complete cessation of spin precession, and in the latter case there is no Thomas precession because of the zero particle velocity and in the initial moment of time spin precession coincides with the Larmor one. Variation of the physical scale and measurement conditions is evidently incapable of ensuring the identity of the measurement results in these two possible extreme situations.

A real experiment on the observation of the relativity principle violation can be carried out at a storage ring with the polarized electron beam in the energy interval 1÷30 MeV by measuring the per-day variation of the resonant frequency of beam depolarization by the external radio-frequency field in the curved sections of its trajectory. Observation of this effect allows one to settle the argument about the existence of a privileged reference frame, which is an initial premise in Lorentz's conception, and to show the road to studying the material structure of physical vacuum, explaining the mechanism of the universal variation of the physical scale of a moving reference system observed in every-day experience, and laying the foundation of consistent mechanics corresponding to material space with the finite velocity of propagation of interactions.

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