Reply to ’Comment for ”Limits on a nucleon-nucleon monopole-dipole (axionlike) P,T-noninvariant interaction from spin relaxation of polarized $^3$He” [arXiv:0912.4963], by A.P. Serebrov’

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Abstract

It is shown, that the criticism, presented in [1] is based on an elementary error in calculation of the collision frequency of an atom in a gas with walls of a container and misunderstanding of the method used in [2] for obtaining constraints on new short-range spin-dependent forces.

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In a recent arXiv preprint [1] A.P. Serebrov published critics of the preprint [2] in which a new limit is presented on the axion-like monopole-dipole P,T-non-invariant coupling in a range $(10^{-4} – 1)$ cm. The limit in [2] was obtained from the existing data on the relaxation rate of spin-polarized $^3$He.

Irrespective of the question if the constraints obtained in [2] are quantitatively correct in all the interaction range, and if the method of the energy shift [3] in the UCN magnetic resonance is more sensitive than the $^3$He spin relaxation method, I would like to show, that the criticism, presented in [1] is based on elementary error in the calculation of the collision frequency of an atom in a gas with walls of a container and misunderstanding of the method used in [2] for obtaining constraints on new short-range spin-dependent forces.

1. The mean diffusion time of an atom from one wall of a cell to another one, which is erroneously taken in [1] as the time between atom collisions with walls is not the time between atom collisions with walls and has not direct relation to the problem, at least in this context.

The wall collision frequency of an atom in a gas confined in a cell of volume $V$ and surface $S$ is $f_{wall} = vS/4V$, where $v$ is the atom velocity, independent of the gas density. For $v_{3He} \approx 1.5 \times 10^5$ cm/s and cylindrical cell diam. 5 cm and length 5 cm $f_{wall} \approx 5 \times 10^3$ s$^{-1}$, compared to typical $\sim 50$ s$^{-1}$ in the UCN chamber.

From this point of view if the spin relaxation in $^3$He is caused by the atom collisions with walls,
the depolarization probability “per one collision with walls” caused by the hypothetic interaction in the polarized $^3\text{He}$ gas is $w = 1/(f_{\text{wall}}T_1) \sim 10^{-12}$. Here the longitudinal spin relaxation time $T_1$ was taken from \[4, 5\] after subtraction of the contribution to the spin relaxation rate from the bulk dipole-dipole relaxation \[6\]: the remaining relaxation time is $T^{\text{rem}}_1 = 4466 \pm 245$ hours for Ref. \[4\], and $T^{\text{rem}}_1 = 2810 \pm 146$ hours for Ref. \[5\].

Again this value should be compared with typical UCN depolarization probability per one collision with walls $\sim 10^{-5}$.

Another interesting figure for comparison: the time spent by particle during spin relaxation in vicinity of the wall, more exactly at a distance from the wall not exceeding the searched spin-dependent interaction range $\lambda$. For small $\lambda$ it is $T_1(\lambda S/V)$, and is $\sim 10^3$ s in a $^3\text{He}$ cell and $\sim 0.05$ s in the UCN EDM chamber.

It is seen that if the spin relaxation were induced by simple spin rotation in the hypothetic spin-dependent field, the $^3\text{He}$ relaxation method would be much more sensitive than the method based on the UCN storage.

But these considerations provoked by \[1\] do not have relation to the the constraints on new spin-dependent interactions \[2\] from spin relaxation of polarized $^3\text{He}$ gas.

2. The depolarization mechanisms of particles in inhomogeneous magnetic (pseudo-magnetic) field in a dense and very rarefied (UCN) gases are somewhat different.

At the very low density, when the free path length between particle collisions with walls is less than between collisions with other particles in a gas, the depolarization probability of a particle spin (ultracold neutron, for example) per one collision with the wall is determined by the expression \[7\]

$$w = \frac{V_0^2 < v_{\perp} >^2 (1 - e^{-d/\lambda})^2}{\lambda^2 \hbar^2 \left( \frac{< v_{\perp} >^2}{\lambda^2} + 4 \omega_0^2 \right)},$$

where $\omega_0 = \gamma_n B$ is the neutron spin Larmor frequency in the external field $B$, $\gamma_n$ - the gyromagnetic ratio for the particle, $< v_{\perp} >$ is the averaged over the particle spectrum normal to the surface particle velocity component, and the the monople-dipole (axion-like) potential between the layer of substance and the nucleon separated by the distance $x$ from the surface is:

$$V(x) = \mp 2\pi g_s g_p \kappa \lambda N e^{-x/\lambda}(1 - e^{-d/\lambda}) = V_0 e^{-x/\lambda}(1 - e^{-d/\lambda})$$

where $N$ is the nucleon density in the layer, $d$ is the layer’s thickness, where $g_s$ and $g_p$ are the dimensionless coupling constants of the scalar and pseudoscalar vertices (unpolarized and polarized particles), $\kappa = \hbar^2/(8\pi m_n)$, $m_n$ is the nucleon mass at the polarized vertex, $\lambda = \hbar/(m_a c)$ is the range of the force, $m_a$ - the axion mass.

In a dense gas the rate of spin relaxation in an inhomogeneous magnetic field of nuclei polarized along z-axis is determined by particle collisions in a gas and by the gradient of the field \[8\]:

$$\frac{1}{T^{\text{grad}}_1} = \frac{1}{3} \left( \frac{\partial H_z/\partial x}{H_z^2} + \frac{\partial H_y/\partial y}{H_z^2} \right)^2 < u^2 > \frac{\tau_e}{1 + (\omega_0 \tau_e)^2},$$

2
where \( < u^2 > \) is the mean squared velocity of \(^3\)He atoms in a gas, \( \omega_0 = 2 \mu H_z / \hbar \) is the magnetic resonance frequency in the magnetic field applied along z-axis, \( \tau_c \) is the time between collisions of the \(^3\)He atoms in a gas. Relatively rare collisions with walls are ignored in this consideration.

When spin relaxation is caused by the gradient of spin-dependent potential \( V \), the rate of spin relaxation is

\[
\frac{1}{T_1^{\text{grad}}} = \frac{4}{3} \frac{(\partial V_x / \partial x)^2 + (\partial V_y / \partial y)^2}{(\hbar \omega_0)^2} < u^2 > \frac{\tau_c}{1 + (\omega_0 \tau_c)^2}.
\]

(4)

I understand that the consideration in [2] was not complete (the infinite flat cell was considered instead of finite size cell, which is essential when \( \lambda \) is not very small compared to the cell size) and is not quite correct for small \( \lambda \) because of very different reason.

But critical arguments presented by A.P. Serebrov in [1] are not to the point and contain error.

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