Comment for article “Limits on a nucleon-nucleon monopole-dipole (axionlike) P-,T-noninvariant interaction from spin relaxation of polarized ultracold neutrons” Yu.N. Pokotilovski, arXiv:0902.3425v2

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Limits on a nucleon-nucleon monopole-dipole (axionlike) P,T-noninvariant interaction from spin relaxation of polarized ultracold neutrons

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Abstract

A new limit is presented on the axionlike monopole-dipole coupling in a range $10^{-4} - 1\,cm$. The gradient of spin-dependent nucleon-nucleon potential between neutrons and nucleons of the walls of the cavity containing ultracold neutrons should affect the neutron depolarization probability at their reflection from the walls. The limit is obtained from existing data on the ultracold neutron depolarization probability per one collision with the walls.

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Recently new constraints on axionlike interactions were presented based on the depolarization rate of ultracold neutrons in traps [11]. It was assumed there that when the range of the hypothetical interaction potential $\lambda \sim 10^{-4} - 10^{-2}\,cm$ is small compared to the typical ultracold neutron spin rotation length l, the neutron spin reversal takes place in the region λ in vicinity of the reflecting wall.

Indeed, l is determined by the relation $l \sim v/\omega_0$, where v is the neutron velocity and $\omega_0 = \gamma_n H$ is the precession frequency of the neutron magnetic moment, $\gamma_n \simeq 1.83 \times 10^4\,s^{-1}$ is the gyromagnetic ratio for the neutron, H is the magnetic field, and at $H = 0.02\,G$, and $v = 500\,cm/s$, $l \sim 1\,cm$. But the adiabaticity parameter - the ratio of Larmor frequency to the frequency of rotation of magnetic field in the neutron reference frame - should be very large in this case, because the searched pseudomagnetic potential is a priori assumed to be very small. Therefore the spin relaxation probability for freely moving neutron must be exponentially small. Depolarization occurs due to discontinuity of the time derivative of full spin dependent interaction at neutron surface collision in condition of non- zero gradient of this interaction.

Of course the field is continuous in time, but its derivative is discontinuous as long as the wall collisions take place in a time small compared to ω_0^{-1}.

It is shown here what constraints on this type interaction may be obtained from existing experimental data on spin relaxation of polarized UCN.

The walls of the cell filled with polarized UCN produce gradient of spin dependent potential:

$$\frac{\partial V}{\partial x} = \pm g_s g_p \frac{\hbar^2 N}{8m_n}(1 - e^{-d/\lambda})e^{-x/\lambda}. \tag{3}$$

The action of this gradient of spin-dependent potential on spin relaxation of polarized UCN is equivalent to the action of gradient of magnetic field on magnetic moment.

The rate of spin relaxation of a neutron polarized along z-axis in the gradient of magnetic field is [13]

$$\frac{1}{T_1} = \frac{2}{3}\frac{(\partial H/\partial x)^2}{H_z^2} < u^2 > \frac{\tau_c}{1 + (\omega_0 \tau_c)^2} \tag{4}$$

where $< u^2 >$ is the mean squared velocity of the ultracold neutrons in a storage volume, ω_0 is their Larmor precession frequency in a magnetic field H_z, τ_c is the time between collisions of the neutrons with the walls.

When spin relaxation is caused by the gradient of spin-dependent potential ∇V this expression looks like

$$\frac{1}{T_1} = \frac{2}{3}\frac{(\partial V/\partial x)^2}{(\hbar\omega_0)^2} < u^2 > \frac{\tau_c}{1+(\omega_0\tau_c)^2}. \tag{5}$$

Since the discontinuities in $\partial V/\partial x$ occur at a surface collisions the depolarization process is sensitive only to the field and its gradient at this surface.

Contrary to spin relaxation of polarized ^3He gas [12], where the time τ_c between collisions of the ^3He atoms is very small and the product $\omega_0\tau_c \ll 1$, the time between collisions of the ultracold neutron with the walls is very large ($\sim 0.1\, s$) and at any reasonable value of the magnetic field $\omega_0\tau_c \gg 1$. In this case

$$\frac{1}{T_1} = \frac{2}{3}\frac{(\partial V/\partial x)^2}{\hbar^2\omega_0^4}\frac{< u^2 >}{\tau_c}. \tag{6}$$

On the other hand the spin relaxation time

$$T_1 = \tau_c/\beta, \tag{7}$$

where β is the neutron spin-flip probability per one collision with the walls.

In result the depolarization probability per one neutron collision with the walls is:

$$\beta = \frac{2}{3}\frac{(\partial V/\partial x)^2 < u^2 >}{\hbar^2\omega_0^4}. \tag{8}$$

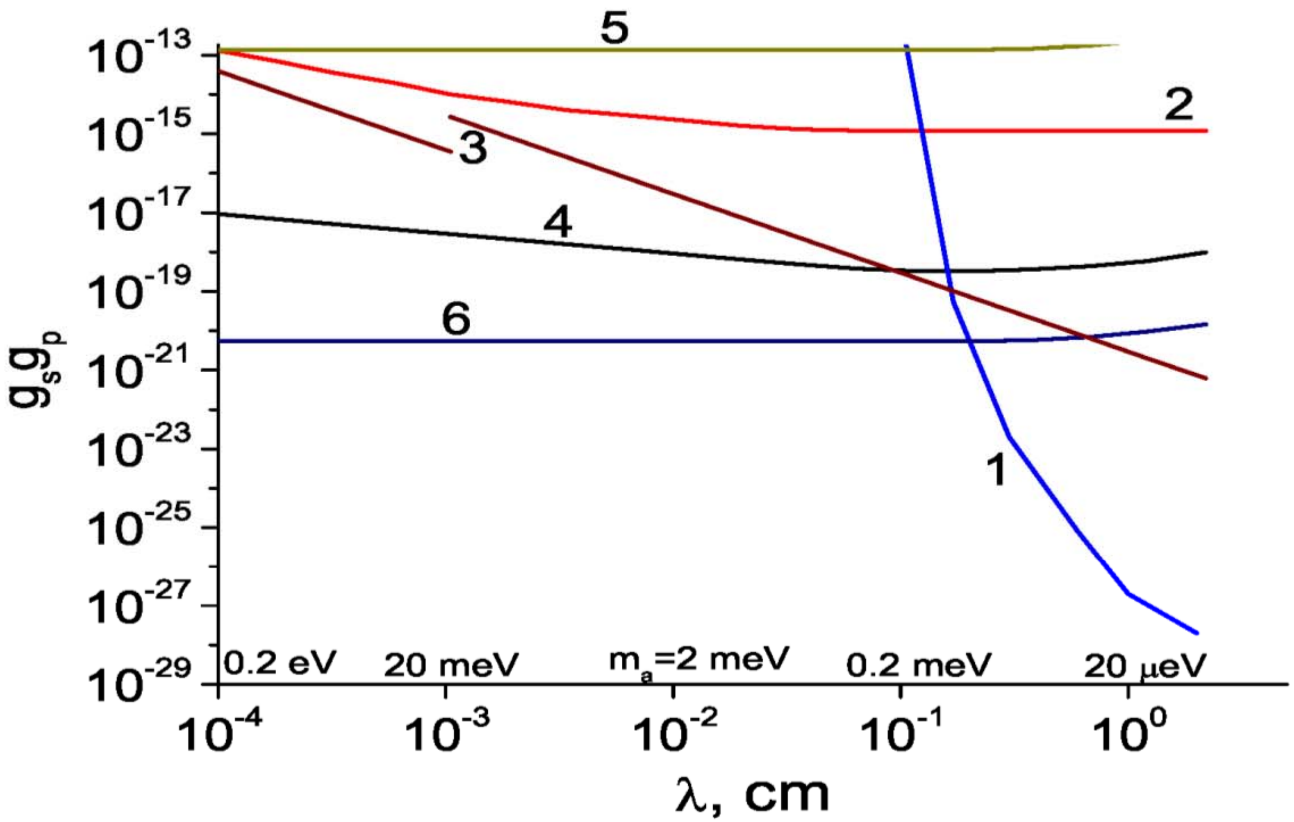

Figure 1: Constraints on the axion monopole-dipole coupling strength $g_s g_p$ and effective range: 1 - from Ref. [21], 2 - from Ref. [10], 3 - from Ref. [11], 4 - from spin relaxation of ^3He, Ref. [12], 5 - this work in an assumption that the UCN depolarization probability $\beta = 10^{-5}$ and magnetic field $H_0 = 50\,G$ [16, 17], 6 - the same, but $H_0 = 0.01\,G$ [20, 19]. It was assumed in all cases of the ultracold neutron storage, that $d = 1\,cm$

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Abstract

In work [1] (Yu. N. Pokotilovski, arXiv:0902.3425v2) restrictions on constants of pseudo-magnetic interaction $g_S g_P$ are presented. These restrictions are considerably differed from restrictions on $g_S g_P$, before published in work [2] (A.P. Serebrov, arXiv:0902.1056v1). Restrictions in work [1] are received from the same experimental data which are used in work [2], however difference in restrictions is considerable. This difference is changed in a range from 1 to 10^7 times depending on value λ. In the given work it is shown that restrictions of work [1] are wrong and the possible reasons of the admitted errors are considered.

Let's consider in more details the task about UCN depolarization at reflection from walls of UCN storage trap (Fig. 1). UCN depolarization arises due to a pseudo-magnetic field near to vertical walls of the tarp, because a pseudo-magnetic field direction is orthogonal to a leading vertical magnetic field H_z. The UCN depolarization effect at one wall collision can be calculated in system of coordinates of a moving neutron and in rotating system of coordinates. The frequency of rotating system of coordinates has to be equal to neutron spin Larmor frequency round a magnetic field H_z. In this system of coordinates the magnetic field H_z appears completely compensated, and the pseudo-magnetic field becomes variable:

$$H(t) = H_r(t)\cos\omega_z t\,, \qquad (1)$$

where $\omega_z = 2\pi\gamma H_z$, γ - neutron gyromagnetic ratio.

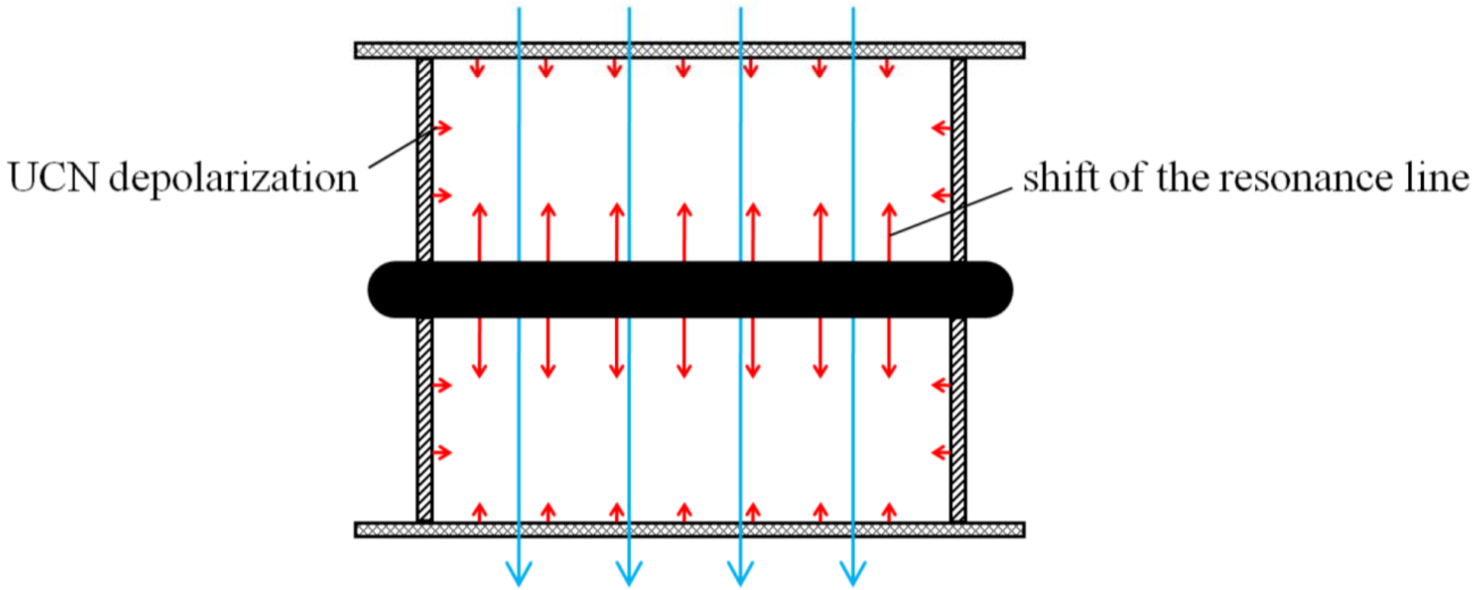


Fig. 1. Scheme of the experiment for neutron electric dipole moment search. The pseudo-magnetic neutron spin precession in the vicinity of vertical walls leads to a random neutron spin flip and UCN depolarization during their storage. The pseudo-magnetic neutron spin precession in the vicinity of horizontal walls will cause the neutron resonance shift, if the central and external electrodes are made from materials of different densities.

The pseudo-magnetic field near to a surface is described by dependence [2]:

$$H(r) = H_{r_0}(\lambda) e^{-|r-r_0|/\lambda}, \qquad (2)$$

where $H_{r_0} = \dfrac{\hbar^2 \lambda}{4 m_{\text{n}} \mu_{\text{n}}} N g_{\text{S}} g_{\text{P}}$ (see [2]).

In system of coordinates of a moving neutron $H(r)$ is transformed to $H_r(t)$:

$$H_r(t) = H_{r_0}(\lambda) e^{-|t|/\tau_\lambda}, \qquad (3)$$

where $\tau_\lambda = \lambda / \text{v}_n$, v_n - normal component of speed to a wall surface.

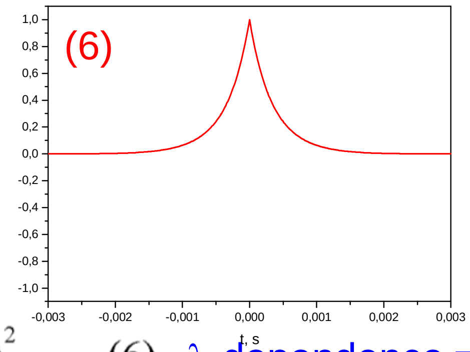
Thus, in rotating system of coordinates of a moving neutron $H(t) = H_{r_0}(\lambda) e^{-|t|/\tau_\lambda} \cos\omega_z t$.

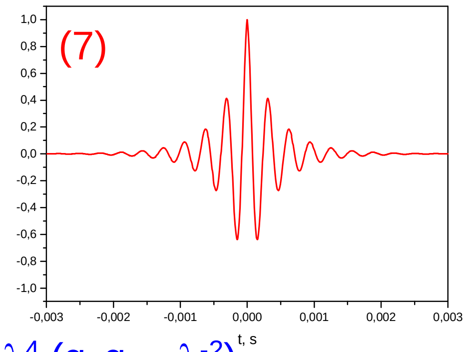
It is necessary to calculate depolarization effect at one wall collision. Polarization on z axis interests us. $P_z = P_0 \cos\theta$, where θ - deviation angle of P_0 from z axis after wall collision. At small angles θ: $P_z = P_0\left(1-\theta^2/2\right)$. Depolarization effect (β) is equal to $\theta^2/2$.

$$\theta = 2\pi\gamma H_{r_0} \int_{-\infty}^{+\infty} e^{-|t|/\tau_\lambda} \cos\omega_z t dt = \frac{4\pi\gamma H_{r_0} \tau_\lambda}{1+\left(\omega_z \tau_\lambda\right)^2} \qquad (4)$$

$$\theta = \frac{2\omega_\lambda \tau_\lambda}{1+(\omega_z \tau_\lambda)^2}, \qquad (5)$$

where $\omega_\lambda = 2\pi\gamma H_{r_0}(\lambda)$.





$$\beta = \frac{1}{2}\left[\frac{2\omega_\lambda \tau_\lambda}{1+(\omega_z \tau_\lambda)^2}\right]^2\Bigg|_{(\omega_z\tau_\lambda)^2 \ll 1} \approx \frac{1}{2}(2\omega_\lambda \tau_\lambda)^2 \qquad (6)$$

λ-dependence = λ^4 ($g_S g_P \sim \lambda^{-2}$)

In work [2] the case of $(\omega_z \tau_\lambda)^2 \ll 1$ is considered. It is a condition of non-adiabatic pseudo-magnetic field occurrence because time of action of a pseudo-magnetic field $2\tau_\lambda$ is much less than rotation period of spin round a magnetic field H_z.

When $(\omega_z \tau_\lambda)^2 \gg 1$, it is a case of adiabatic pseudo-magnetic field occurrence because during pseudo-magnetic field action $2\tau_\lambda$ there are many turns round a magnetic field H_z and the depolarization effect is suppressed.

$$\beta = \frac{1}{2}\left[\frac{2\omega_\lambda \tau_\lambda}{1+(\omega_z \tau_\lambda)^2}\right]^2\Bigg|_{(\omega_z\tau_\lambda)^2 \gg 1} \approx \frac{1}{2}\left[2\frac{\omega_\lambda \tau_\lambda}{(\omega_z \tau_\lambda)^2}\right]^2 \qquad (7)$$

λ-independent ~ const ($g_S g_P \sim$ const)

In work [1] the second case is wrongly chosen, because instead of τ_λ it was considered τ_c (time between neutron collisions with walls). Besides, in work [1] condition of adiabaticity is accepted a priori on a condition $H_\lambda / H_z \ll 1$. It is necessary, but not a sufficient condition of adiabaticity. As a result, in work [1] the formula for adiabatic case is applied though actually the case is non-adiabatic $(\omega_z \tau_\lambda)^2 \ll 1$. The small parameter $\omega_z \tau_\lambda$ appears in a power of 4 in a denominator of the formula (7). It leads to an error of big orders.

Besides, from the formula (7) follows that the depolarization probability does not depend from λ because ω_λ and τ_λ are proportional λ. This erroneous conclusion of independence from λ is transferred on restrictions on $g_S g_P$ as it is seen in Fig. 2. (Fig. 1 from work [1].) In Fig. 2 constraints from work [2] correspond to curve 3, constraints from work [1] correspond to curve 6.

Certainly, at reduction of λ divergence degree between formulas (6) and (7) increases reaching 7 orders of magnitude. ($\omega_z \tau_\lambda$ becomes ever less, but adiabatic case is used.)

For example, it is easy to calculate deviation angle of vector P_0 from z axis for $\lambda = 10^{-4}$ cm and $g_S g_P = 10^{-20}$ (an extreme point at the left in Fig. 2):

$$\theta = \frac{2\omega_\lambda \tau_\lambda}{1+\left(\omega_z \tau_\lambda\right)^2} \approx 2\omega_\lambda \tau_\lambda = 2.2\cdot 10^{-10}\ \text{rad}.$$

Accordingly, the depolarization effect ($\beta = \theta^2/2 = 2.5\cdot 10^{-20}$) is less on 15th orders of magnitude than experimental value $\beta_{\exp} = 10^{-5}$, but in work [1] experimental value 10^{-5} was used to obtain constraints for $g_S g_P = 10^{-20}$ at $\lambda = 10^{-4}$ cm. This estimation is the obvious proof of abnormality of restrictions on size of $g_S g_P$ in work [1].

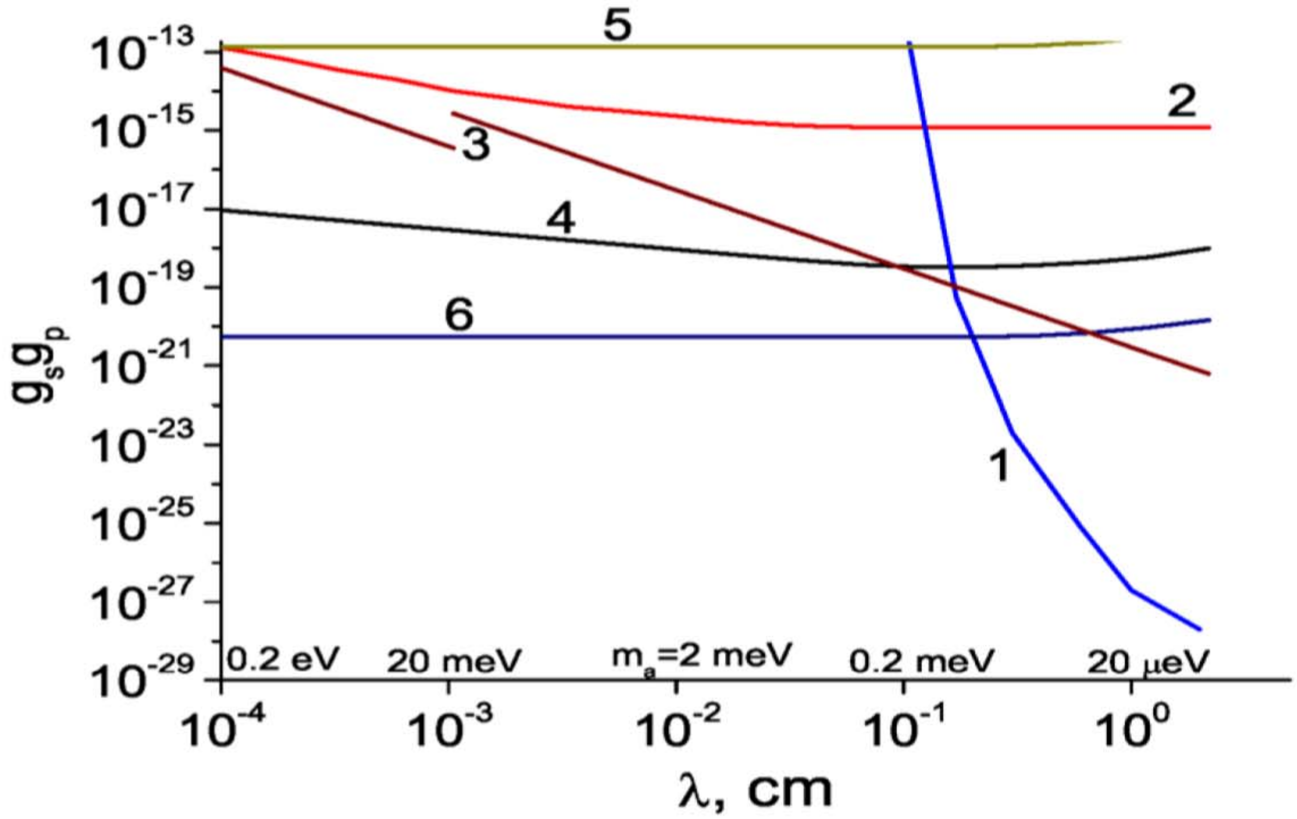


Fig. 2. Constraints on the axion monopole-dipole coupling strength $g_S g_P$ and effective range: 1 - from Ref. [4], 2 - from Ref. [5], 3 - from Ref. [2], 4 - from spin relaxation of ^{3}He, Ref. [3], 5 – work [1] in an assumption that the UCN depolarization probability $\beta = 10^{-5}$ and magnetic field H_z =50 G [6,7], 6 - the same, but H_z =0.01 G [8,9].

In summary it is necessary to notice that in work [3] ("Limits on a nucleon-nucleon monopole-dipole axionlike P-,T-noninvariant interaction from spin relaxation of polarized He-3", Yu.N. Pokotilovski, arXiv:0902.1682v2) the same formulas, as in work [1] were applied. It raises the big doubts in justice of conclusions of work [3] also.