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The Laue diffraction method to search for a neutron EDM. Experimental test of the sensitivity

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Abstract

The feasibility of an experiment to search for the neutron electric dipole moment (EDM) by Laue diffraction in crystals without a center of symmetry was tested. At the PF1A beam of the ILL reactor a record time delay of $\tau \approx 2$ ms for the passage of neutrons through a quartz crystal was reached for the (1 1 0) plane and diffraction angles equal to 88.5°. That corresponds to an effective neutron velocity in the crystal of 20 m/s, while the velocity of the incident neutron was 800 m/s. It was shown experimentally that the value $\tau N^{1/2}$, determining the method's sensitivity, has a maximum for the Bragg angle equal to 86°. The results allow us to estimate the statistical sensitivity of the method for the neutron EDM. For the PF1B beam of the ILL reactor the sensitivity can reach $\sim 6 \times 10^{-25}$ e cm per day for the available quartz crystal.

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1. Introduction

The question of the existence of a non-zero electric dipole moment (EDM) is in the focus of hot physical discussions during practically 50 years, started by the pioneering experiment of Smith, Purcell, and Ramsey in 1957 [11]. The current best limit of $d_n < 0.63 \times 10^{-25}$ e cm (at 90% c.l.) [4], obtained at the ILL reactor in Grenoble in 1999, is result of long-term efforts of different groups working at the PNPI and ILL reactors [5,6]. A finite value or new limits on the EDM would be of great importance for understanding the nature of CP violation as well as of the baryon asymmetry in the Universe. Practically all previous experiments and even the new projects were based on the same magnetic resonance method of Ramsey, using first cold and then ultra cold neutrons (UCN method). In this situation, an alternative method with a comparable statistical sensitivity

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but different systematics is needed to perform independent checks.

We discuss here the statistical sensitivity of such a new method [1] that uses Laue diffraction of neutrons in non-centrosymmetric crystals. The method is based on the interaction of neutrons with an inter-planar electric field of a non-centrosymmetric crystal. The value of this field can exceed 10^8 V/cm [3]. These fields were discovered experimentally for the (1 1 0)-plane of an α-quartz crystal [3]. However, the value of the crystal field turned out to be still insufficient to reach the sensitivity of the UCN method by standard diffraction. The essential feature of the proposed Laue diffraction geometry with Bragg angles close to 90° is the possibility to increase the time τ of the neutron passage through the crystal substantially [2]. This time corresponds to the interaction time of the neutron with the electric field and goes directly into the sensitivity of the method.

The first experiments to test the new method were carried out at the WWR-M reactor in Gatchina (Russia). A large ($14 \times 14 \times 3.5$ cm^3) perfect non-centrosymmetric α-quartz crystal and a forward diffracted beam were used for these measurements. The preliminary results have proved all phenomena predicted earlier, such as the depolarization of the neutron beam in Laue diffraction [8,10], a considerable delay of the diffracted neutron inside the crystal for Bragg angles close to 90° [8,9], and the independence of the electric field (of about 2.2×10^8 V/cm) affecting the diffracted neutron on the Bragg angle up to angles equal to 87°. The detailed test of the statistical sensitivity of the method presented in this paper was recently carried out at the ILL reactor in Grenoble (France).

2. Laue diffraction method of the neutron EDM search

Here we consider the Laue diffraction of neutrons in a non-absorbing crystal without a center of symmetry under exact Bragg condition [1,7].

The diffracted neutrons in two Bloch states $\psi^{(1)}$ and $\psi^{(2)}$ are moving under opposite electric fields $\pm E_g$ in the crystal [2,3]. The spins in these states will be rotated due to "Schwinger" interaction in opposite directions, leading to a decrease of the effective neutron beam polarization.

If the initial spin orientation is normal to the "Schwinger" magnetic field $\mathbf{B}_g = \pm[\mathbf{E}_g \times \mathbf{v}]/c$, then the value of the effective neutron beam polarization P is decreased down to zero for a crystal thickness L_0 corresponding to spin rotation angles of $\pm\pi/2$ ($L_0 = 3.5$ cm for the (1 1 0)-planes of α-quartz). For a crystal thickness of $2L_0$ the neutron beam polarization is inverted with respect to the initial polarization.

The existence of an EDM would lead to the appearance of a slight beam polarization along the Schwinger magnetic field $\mathbf{B}_g$ (for more details, see [8,7]). The maximum value of this polarization is reached for a crystal thickness equal to $2L_0$:

$$P_{\mathrm{EDM}} = \frac{2E_{\mathrm{EDM}}}{E_{\mathrm{Schwinger}}} = \frac{2c}{v_\parallel}\frac{d_n}{\mu_n} = 3 \times 10^{22}\left[\frac{\mathrm{m/s}}{\mathrm{e\,cm}}\right]\cdot\frac{d_n}{v_\parallel}, \tag{1}$$

where E_{EDM} and $E_{\mathrm{Schwinger}}$ are the energy of the neutron EDM interaction and the Schwinger interaction, respectively, c the speed of light, μ_n the neutron magnetic moment, and $v_\parallel$ the component of the neutron velocity parallel to the (1 1 0) plane.

The principal scheme of the method is shown in Fig. 1. For two crystal positions A and B with the same Bragg angle but with opposite directions of the electric field, the polarization P_{EDM} will have opposite signs whereas a residual polarization will have the same sign for both crystal positions.

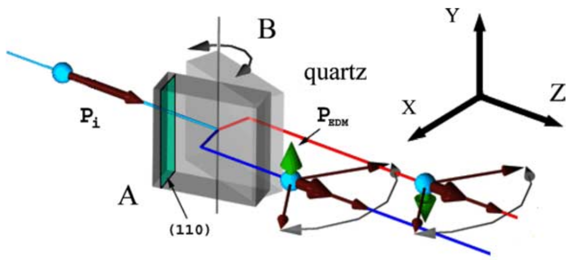

Fig. 1. Scheme of the method for a neutron EDM search by Laue diffraction. The presence of a neutron EDM will lead to a small Y-component of the polarization, which will have different signs for the two crystal positions A and B.