POLARIZATION METHOD OF MEASURING STRONG ELECTRIC CRYSTAL FIELDS IN NEUTRON DIFFRACTION

V. V. Fedorov, E. G. Lapin, V. V. Voronin

A new method is proposed for measuring strong electric fields which affect the neutrons diffracted by noncentrosymmetric quartz-crystal for Bragg angles close to $\pi/2$. The method is based on the effect of depolarization of the diffracted neutron beams (direct and reflected) passed through the crystal. Description of the effect and the set-up for its measurement is given.

Recently a new diffraction method was proposed [1] for neutron EDM searching. It was based on interaction of the EDM with a strong electric crystal field during neutron Laue-diffraction in a crystal without centre of symmetry. The principle possibility was shown to exceed the sensitivity of the most sensitive now magnetic resonance method using ultracold neutrons (UCN-method) [2, 3].

The electric field that affects the neutrons during the whole time of their diffraction (on the way up to 10 cm) has a value of about 10^8 V/cm. It is more than 10^4 times greater than the fields used in the UCN-method [2, 3]. It was measured in our experiment [4] for $(11\bar{2}0)$-plane of α-quartz crystal as a pendulum phase shift caused by the spin flip (due to the Schwinger interaction of diffracted neutrons). The experimental value of the electric field E_g had coincided with the calculated one and turned out to be equal to $E_{11\bar{2}0} = (1.8 \pm 0.2) \cdot 10^8$ V/cm.

An important one is a real possibility to increase essentially the time τ of a neutron passage through the crystal using Bragg angles θ_B close to $\pi/2$, because the diffracted neutrons are moving in the average along the crystallographic planes with the corresponding velocity $v_{||} = v \cdot \cos\theta_B$ that is determined by the Bragg angle and so can be decreased at least by an order compared with the total neutron velocity. Therefore, the values $E\tau$ [1)]can be of the same order for UCN and diffraction method (for Bragg angles sufficiently close to $\pi/2$) [1] despite the fact that the storage time for UCN is essentually more than that for neutron passage through the crystal.

Since the use of angles close to $\pi/2$ may increase (by an order or more) sensitivity of the method, at first we plan to create the simplest set-up for measuring interplanar electric fields acting on neutrons in the quartz crystals, for different Bragg angles close to $\pi/2$. That makes possible to find experimentally how close can we approach the Bragg angle to $\pi/2$ for available crystals with different degree of perfection with large value E being saved, i.e. to ascertain for what Bragg angles and crystal mosaicity the crystal imperfections begin to destroy the fields in this condition. So we can determine experimentally the maximal sensitivity (namely, the maximum value $E_g\tau$) attainable in this method of EDM measurements and the possibility of selection of sufficiently perfect crystals.

For this purpose we are going to measure the value E for different angles $\tilde{\theta}_B$ using a simple one-crystal variant of the set-up. The idea of the device is based on a new effect of depolarization of an initially polarized neutron beam during Laue diffraction in a crystal without centre of symmetry (quartz, for example) due to the Schwinger interaction of neutron

[1)]The set-up sensitivity is determined by $\sigma(D) \propto 1/E\tau\sqrt{N}$ where $\sigma(D)$ is an absolute error of EDM measurement, N is a total number of accumulated events.

magnetic moment with electric crystal field. Essence of the effect is as follows. The two Bloch states of diffracting neutron are moving in opposite electric fields in crystal [1, 4, 5], therefore spins in these states are rotating in opposite directions, that leads to a decrease of the effective neutron beam polarization. If initially spin orientation is normal to the "Schwinger" magnetic field, then the spin rotation angle α will be [1, 5]:

$$\alpha = \pm \frac{g_n e E_g L}{m_p c^2}, \tag{1}$$

where the signs $\pm$ are related to states (1),(2) respectively, $g_n = -1.9$ is the neutron magnetic moment in nuclear magnetons, e is the electron charge, E_g is the electric field acting on neutrons, L is crystal thickness, m_p is the proton mass, c is the light velocity. The value of neutron beam polarization P depends on α in the following way:

$$P = P_0 \cos \alpha, \tag{2}$$

P_0 is the incident beam polarization.

The polarization P can be decreased down to zero by the choice of such a crystal thickness $L_0 = \pi m_p c^2 / 2 g_n e E_g$ that makes the spin rotation angles equal to $\pm\pi/2$. For $(11\bar{2}0)$-planes of α-quartz $L_0 = 3.6$ cm. We can determine the electric field measuring the polarization of any diffracted beam (direct or reflected). First we plan to use the direct beam. So the set-up (see Fig.) will consist of two short (400 mm) multy-slit polarizing neutron guides (one of them is a polarizer, and the second is an analyzer), two spin flippers, correctly cutting a crystal of quartz (placed in magnetic shield), a precise angle measurement device, neutron detectors, CAMAC electronics and a computer. The spin flippers are necessary because for spin parallel to direction $[\boldsymbol{v} \times \boldsymbol{E}]$ there is no effect of depolarization while for spin perpendicular to this direction the effect is maximal. We can compare the detector counting rates for these two spin orientations to determine the electric field acting on the neutrons.

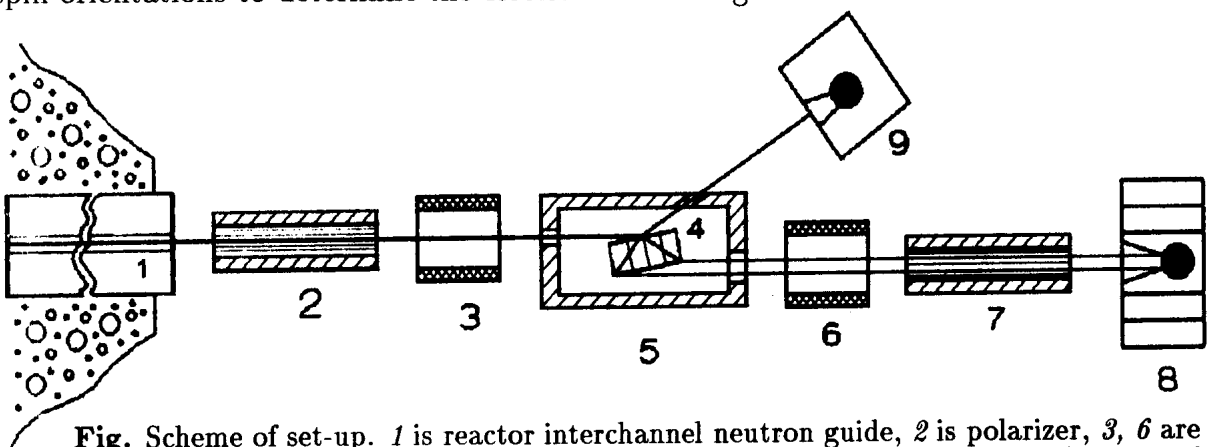

Fig. Scheme of set-up. *1* is reactor interchannel neutron guide, *2* is polarizer, *3, 6* are flippers, *4* is quartz single crystal, *5* is magnetic shield, *7* is analyzer, *8* is detector, *9* is beam monitor.

In the case represented in Fig. the Schwinger magnetic field $\boldsymbol{H}_g^S = [\boldsymbol{E}_g \times \boldsymbol{v}_{||}]/c$ acting on the neutrons is directed perpendicular to the figure plane. If the neutron spin (after polarizer) is laying in this plane and is normal to the neutron momentum, then the counting rate of the detector (for analyzer orientation parallel to that of a polarizer and for flippers being switched out) will be

$$N = N_0 \cos^2 \frac{\alpha}{2} = N_0 \cos^2 \left(\frac{g_n e E_g L}{2 m_p c^2}\right), \tag{3}$$

where N_0 is intensity of polarized neutron beam after a polarizer, which, for example, can be measured by a monitor. For crystal thickness L_0 corresponding to spin rotation angle $\alpha = \pi/2$ the detector will detect a half intensity N_0 detected by the monitor. That has a simple physical meaning of a probability to find the spin projection parallel to its initial direction. For crystal thickness $L = 2L_0$, the spins will be rotated by the angle π, i.e. will be oriented in the direction opposite to their initial one. Neutrons will not reach the detector in this case. That corresponds to zero probability of the spin projection to be parallel to its initial direction.

For a given crystal thickness we shall get a definite counting rate that will not depend on the Bragg angle within some angle interval. With approaching the Bragg angle to $\pi/2$ the counting rate may start to increase from the angle θ_B^c. That will correspond to beginning of destruction of electric fields connected with crystal imperfections. The angle θ_B^c determines the maximum value $E\tau$ (and so the set-up sensitivity) that one can reach using this method. The flippers allow to measure the beam polarization and to take it into account for determination of electric field acting on the neutrons.

At the end we note that with Bragg angle increasing and approaching $\pi/2$ the angle period of pendulum oscillations becomes less than the angle diffraction width [1]. The scheme of experiment used in works [4, 5] becomes unacceptable in principle for this condition because the effects disappear being averaged over the fast angle oscillations. The two crystal set-up [1] was proposed to measure the effects connected with the crystal electric fields in this case. There is also the other method to perform such measurements. It is the polarization method described above, which we are going to use for field measurements at Bragg angles close to $\pi/2$. The importance of polarization experiments is also determined by their less sensitivity to crystals quality that may make the selection of proper crystals more easy.

The authors are grateful to O.I.Sumbaev for consultations and useful discussions.

REFERENCES

1. *Fedorov V.V., Voronin V.V., Lapin E.G.* Preprint LNPI–1644. Leningrad, 1990. 30 p.
   Fedorov V.V. // Elementary Particles Physics: Proc. of the XXVI LNPI Winter School. LNPI. Leningrad, 1991. Part 1. P.65.
   Fedorov V.V., Voronin V.V., Lapin E.G. // J.Phys.G: Nucl.Part.Phys., 1992. V.18. P.1133–1148.
2. *Altarev I.S., Borisov Yu.V., Borovikova N.V., Ivanov S.N., Kolomenskii E.A., Lasakov M.S., Lobashev V.M., Pirozhkov A.N., Serebrov A.P., Sobolev Yu.V., Shul'gina E.V.* // LNPI Research Report 1988–1989. Leningrad, 1990. P.6.
3. *Thompson D.* // Nucl.Instr.Meth., 1989. V.A284. P.40.
   Smith K.F., Crampin N., Pendlebury J.M., Richardson D.J., Shiers D., Green K., Kilvington A.I., Moir J., Prosper H.B., Thomson D., Ramsey N.F., Heckel B.R., Lamoreaux S.K., Ageron P., Mampe W., Steyerl A. // Phys.Lett., 1990. V.B234. P.191.
4. *Alexeev V.L., Fedorov V.V., Lapin E.G., Leushkin E.K., Rumiantsev V.L., Sumbaev O.I. and Voronin V.V.* // Nucl.Instr. and Meth., 1989. V.A284. P.181.
   ZhETF, 1989 V.96. P.1921.
5. *Alexeev V.L., Voronin V.V., Lapin E.G., Leushkin E.K., Rumiantsev V.L., Fedorov V.V.* Preprint LNPI–1608. Leningrad, 1990. 12 p.