Detection of linear polarization of gamma radiation with planar electron channeling in diamond

Yu. N. Adishchev, I. E. Vnukov, S. A. Vorob'ev, V. M. Golovkov, V. N. Zabaev, V. I. Lunev, A. A. Kurkov, B. N. Kalinin, and A. P. Potylitsyn
Institute of Nuclear Physics of the S. M. Kirov Tomsk Polytechnic Institute

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A linear polarization of the gamma radiation, which appears with planar electron channeling in diamond, has been detected in a measurement of the asymmetry of the photoneutron yield of the (γ, n) reaction in a D_2O target.

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Many theoretical papers, for example, Refs. 1 and 2, have predicted that intense γ radiation produced by planar channeling of electrons has a high degree of linear polarization; until now, however, these conclusions have not been confirmed experimentally.

We present in this paper the first results of measurements which prove the presence of a linear polarization of γ radiation arising from planar channeling of electrons with an energy $E_0 = 900$ MeV in a 0.35-mm-thick diamond single crystal.

The radiation spectrum, which was measured by a ϕ 200 X 200-mm NaI (Tl) spectrometer, is shown in Fig. 1. The experimental method was described in detail in Ref. 3. As follows from Fig. 1, the maximum in the γ-radiation spectrum for electron channeling along the (110) crystal plane corresponds to an energy $\omega_0 = 4$ MeV. The method suggested in Ref. 4 is the most suitable for analyzing linear polarization in this energy region. This method consists of recording the products of deuteron (in our case neutron) photodisintegration. The analyzing capacity of this process

$$\gamma d \rightarrow pn \tag{1}$$

is close to unity in the energy range of γ-ray quanta $4 \leqslant \omega \leqslant 12$ MeV.[4,5]

A deuteron-containing target in the form of D_2O, which was enriched with deuterium to 99.5% and enclosed in a glass ampoule with a diameter of 10 mm and a length of 100 mm, was used in the experiment (whose arrangement is shown in Fig. 2). The characteristics of the electron beam and of the equipment were published previously.[6] The effective collimation of the γ-ray beam, which was determined by the D_2O-target diameter, was equal to ~0.3 mrad. The neutrons were detected by an SNM-11 slow-neutron counter in a paraffin moderator (an "all-wave" neutron counter), whose detection efficiency was constant in the neutron-energy interval from a few keV to 4-5 MeV.[7] The capture angle of the neutron detector was 16°. The single crystal was oriented by means of a thin-wall ionization chamber (IC) that was sensitive to the low-energy part of the γ-ray spectrum. A similar procedure was de-

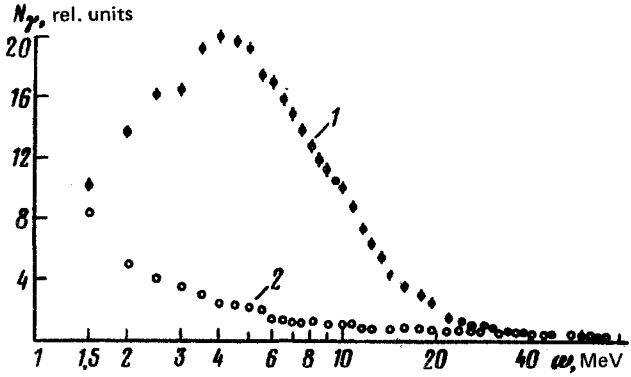

FIG. 1. Instrumental spectra of the γ radiation of 900-MeV electrons channeled in a diamond. 1—for (110) plane, 2—disoriented diamond, $\psi_b = 1$ mrad and $\psi_\Gamma = 5$ mrad.

scribed in Ref. 8. A synchrotron-radiation sensor[3] was used to monitor the accelerated-electron current. The maxima in the orientational dependence of the IC current (Fig. 3) are caused by γ radiation of the electrons that are captured in the planar-channeling regime.

In the experiment we measured the azimuthal asymmetry A_D of the neutron yield from the deuterium nuclei at a polar angle $\theta = 90°$ in two mutually perpendicular planes,

$$A_D = \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}, \tag{2}$$

where $N_{\parallel(\perp)} = N_{\parallel(\perp)D_2O} - N_{\parallel(\perp)H_2O}$ is the neutron yield from the D_2O target, taking into account the background in the plane that is parallel (or perpendicular) to the plane of electron oscillations. The background was determined from the yield of an H_2O target with identical dimensions. The oxygen contribution is strongly suppressed, since it is caused by γ-ray quanta with an energy $\omega \gtrsim 16$ MeV; in addition,

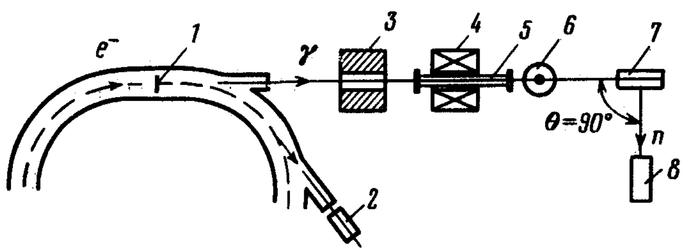

FIG. 2. Experimental setup. 1—diamond target, 2—synchrotron-radiation detector, 3—collimator, 4—cleaning magnet, 5—evacuated tube, 6—thin-wall ionization chamber, 7—neutron target, 8—SNM-11 neutron counter.

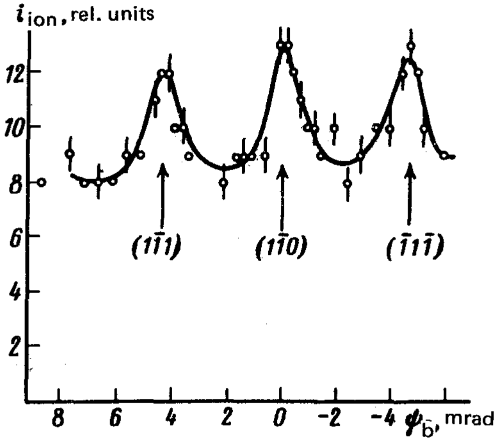

FIG. 3. Orientational dependences of ionization-chamber current on the crystal-orientation angle ψ_b for $\psi_\Gamma = 5$ mrad.

the asymmetry of the neutron yield from oxygen is assumed to be small because of the multiparticle nature of the process.[7] The experimental value of the asymmetry is related to the linear polarization of the γ radiation in the following manner:

$$A_D = \bar{P}\bar{R} ; \quad (3)$$

here $\bar{P}$ is the degree of linear polarization averaged over the γ-radiation spectrum and $\bar{R}$ is the average analyzability of the process (1), which is $\bar{R} = 0.94 \pm 0.06$ for the spectrum (curve 1 in Fig. 1), according to our calculations. It must be pointed out that rescattering of the neutrons in the target, with a probability of 15% in our case, was ignored in the calculation of the analyzability $\bar{R}$.

A total of four independent measurements of the A_D coefficient were made. At least 600 events were collected for each detector position. The instrumental asymmetry, which was measured for the following experimental cases: a) D_2O target, Schiff spectrum of an amorphous target; b) D_2O target, spectrum of a disoriented diamond target (curve 2 in Fig. 1), was equal to zero within the statistical-error limits.

The measurements produced the following value for the average degree of polarization of the γ radiation of electrons that channel in the (110) plane: $\bar{P} = 0.80 \pm 0.15$. The statistical error, the systematic error associated with uncertainties in the placement of targets and detector, and the error in estimating the analyzability are included in the total error.

A control measurement of the γ-ray polarization for electron channeling in the (001) plane was also carried out by us. Since this plane was rotated by 90° relative to the (110) plane, the γ-radiation polarization plane must also be rotated. The results of the measurements confirmed this assumption: the direction of preferential escape of the neutrons was changed by 90°. The degree of polarization of this plane, which was calculated with the same assumptions as before, is $\bar{P} = 0.65 \pm 0.15$. The difference in the average degrees of polarization can be explained by the difference in the interplane potentials of the (110) and (001) planes, on which the capture efficiency in the channel and the shape of the γ-radiation spectrum depend.

A high-intensity, quasi-monochromatic, γ-ray beam with high linear polarization can be used to study various photonuclear reactions and in nuclear spectroscopy. The beam parameters can be changed simply by rotating the single-crystal target; in this way, it is easy to change the orientation of the polarization plane of the γ radiation. In contrast to the coherent bremsstrahlung mechanism,[9] high intensity and a high degree of linear polarization can be combined for the γ radiation of electrons with planar channeling.

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