Fast-neutron scattering in crystals

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The scattering of fast neutrons in a germanium single crystal is studied. The experimental results show that aligning a crystallographic axis with the direction of the neutrons gives rise to an additional scattering.

As fast neutrons move through a crystal, the long-range electromagnetic (Schwinger) interaction[1] could in principle, by analogy with the channeling of charged particles, give rise to structural features by virtue of the orientation of a crystallographic axis with respect to the incident beam. This possibility has been discussed theoretically, in particular, in Refs. 2–5.

In the present letter we report an experimental study of this question. In planning the experiment we worked from the calculations of Refs. 2 and 3 on the elastic scattering of a beam of fast neutrons which are incident on an atomic row at an angle θ. In this case, coherence conditions are satisfied for scattering in directions that form a conical surface with a vertex angle θ around the atomic row. This coherence gives rise to an additional scattering and, in view of the Schwinger interaction, a dependence of the total scattering cross section on the angle between the crystallographic axis and the direction of the neutron in the arc-minute region. This dependence was investigated by us experimentally.

The experiments were carried out in the apparatus shown in Fig. 1, positioned in a horizontal channel of the VVR-M reactor of the Institute of Nuclear Research of the Academy of Sciences of the Ukrainian SSR. The neutron beam is collimated by two steel collimators each 2000 mm long with a channel (the dot-dashed line) 3×3 mm^2 in size. The test sample is mounted on a goniometer, which can be rotated with a precision $\sim 1'$, between these collimators. The neutrons are detected by a scintillation de-

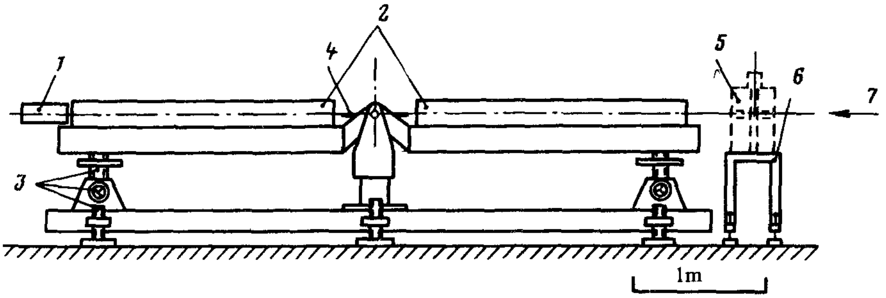

FIG. 1. The experimental apparatus. 1—Detector; 2—collimators; 3—adjustment apparatus; 4—goniometer with sample; 5—^{198}Au source; 6—adjustment stand; 7—neutron beam.

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tector, with pulse shape discrimination of the signals from fast neutrons and γ rays. The effective energy of the neutrons is ~ 3 MeV; the energy spread is of no major importance in this problem.

The test sample is a germanium single crystal with a mosaic angle $< 40''$ and a thickness of 56 mm. Two cuts are made in the crystal before the measurements; the planes of these cuts agree within $\sim 1'$ with the (111) and (220) crystallographic planes. The $[1\bar{1}0]$ axis at their intersection is aligned with the axis of the collimators. Further control and final adjustment of the single crystal are made possible by γ-ray diffraction in the same apparatus (Fig. 1). For this purpose a γ-ray beam from a ^{198}Au source (activity ~ 30 Ci, $E_\gamma = 412$ keV) is passed through the collimators. The crystal is then rotated in the vertical or horizontal plane, and the minima which are caused in the count rate of the transmitted beam by diffraction by the crystallographic planes (as the angle is varied) are observed. The positions of these minima are used to orient the $[1\bar{1}0]$ axis along the beam within $\sim 1'$, and the half-widths of these minima are used to estimate the angular resolution of the apparatus: $\sim 3'$.

The main experiment can be summarized as follows: After adjustment by the method described above, we study the count rates of the fast neutrons transmitted through the single crystal while varying the angle at which they enter the crystal with respect to the $[1\bar{1}0]$ axis. The crystal is rotated in the (111) horizontal plane over an angular interval $\pm 40'$. The measurement procedure and control experiments are described in detail in Ref. 6.

The experimental results are shown in Fig. 2; the indicated errors are statistical, based on a normal distribution. We can draw several conclusions from these results.

1) There is a clearly defined minimum in the angular dependence of the count rate.

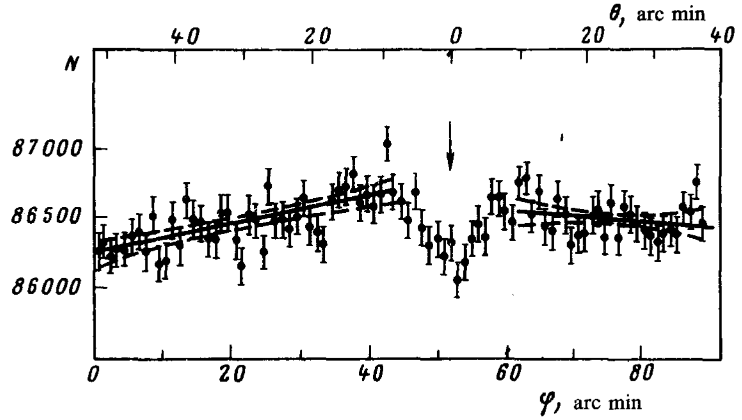

FIG. 2. Fast-neutron count rate versus the angle at which the neutrons enter the crystal, measured from an axis. The upper abscissa scale shows the angle reckoned from the [110] direction along the beam, as determined from γ-ray diffraction. Away from the minimum, the data can be described well by straight lines, which are shown along with the 95% confidence interval.

2) The position of this minimum agrees within $\sim 1'$ with the direction of the crystallographic axis along the neutron beam. This direction was determined independently on the basis of γ-ray diffraction.

3) The additional scattering which is observed corresponds to a cross section $\sim 3\times 10^{-26}$ cm^2, in comparison with a total cross section $\sim 4\times 10^{-27}$ cm^2 for Schwinger scattering by germanium.

At the angular resolution and accuracy of this experiment, these results agree with the calculations of Refs. 2 and 3 on neutron scattering by isolated atomic rows, and they agree well with the results of Ref. 5, which take into account the mutual effects of the atomic rows. The fact that the intensified scattering observed experimentally is a due to the direction of the crystallographic axis was confirmed by a special experiment in which we moved the axis $\pm 5'$ away from the neutron beam in the vertical plane and repeated the measurements. We found no dependence of any sort of the count rate on the angle.

In summary, we have experimentally observed an additional scattering of fast neutrons in a germanium crystal, which occurs when a crystallographic axis is aligned with the neutron direction. These results can be explained theoretically.

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