FAST NEUTRON AND GAMMA-RAY CHANNELING IN CRYSTALS

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The possibility of channeling for neutrons and γ-rays in the MeV range where the momentum transfer is much greater than distances in the reciprocal lattice was studied theoretically by a number of authors [1–4]. It has been shown [1] that the contribution of the electromagnetic (Schwinger) interaction to the total cross section of scattering increased tens times owing to interference effects when fast neutrons are incident upon a single crystal at the small angle ($\sim 1'$) in relation to the crystallographic axis.

Taking into account theoretical groudns, the authors set a number of experiments with a view to reveal the predicted effects.

An experimental study has been carried out of the effect of germanium and antimony single crystal orientation on the transmission of strongly collimated fast neutron and gamma-ray beams [5–8].

Figs.1 and 2 show the results of measurements for fast neutrons. Here and in what follows statistical errors are specified. The data presented can be summarized as follows:

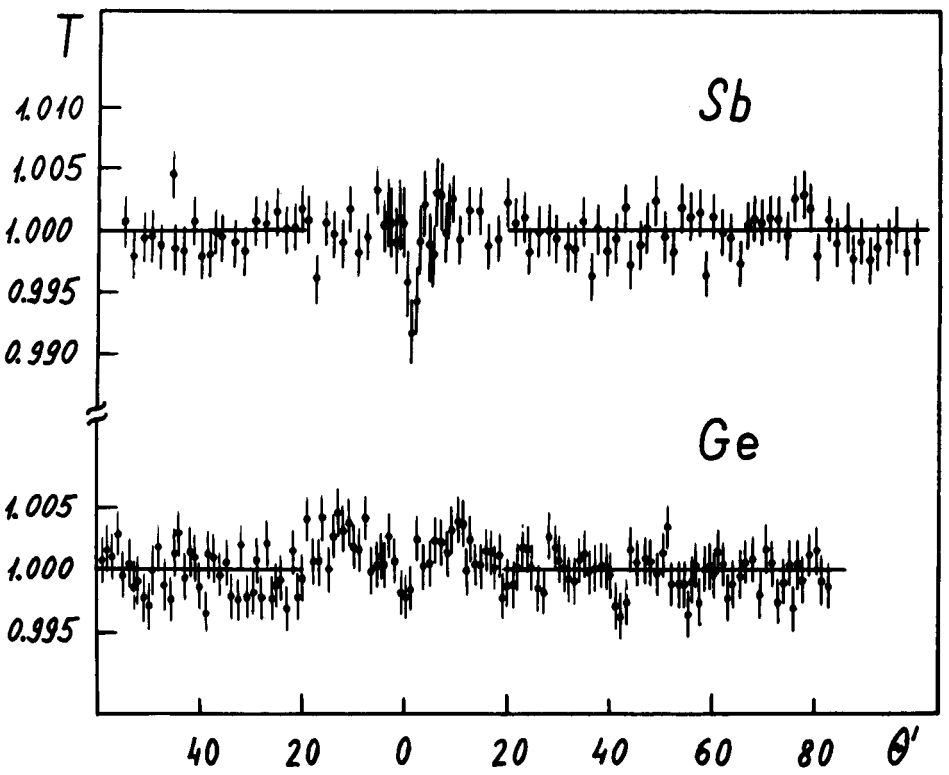

Fig.1. Fast neutron transmission coefficient versus incidence angle relative to $[1\bar{1}0]$ and [110] axes for Sb and Ge respectively. The angle $\Theta = 0$ corresponds to the crystal axis aligned along the beam as determined from γ-ray diffraction measurements

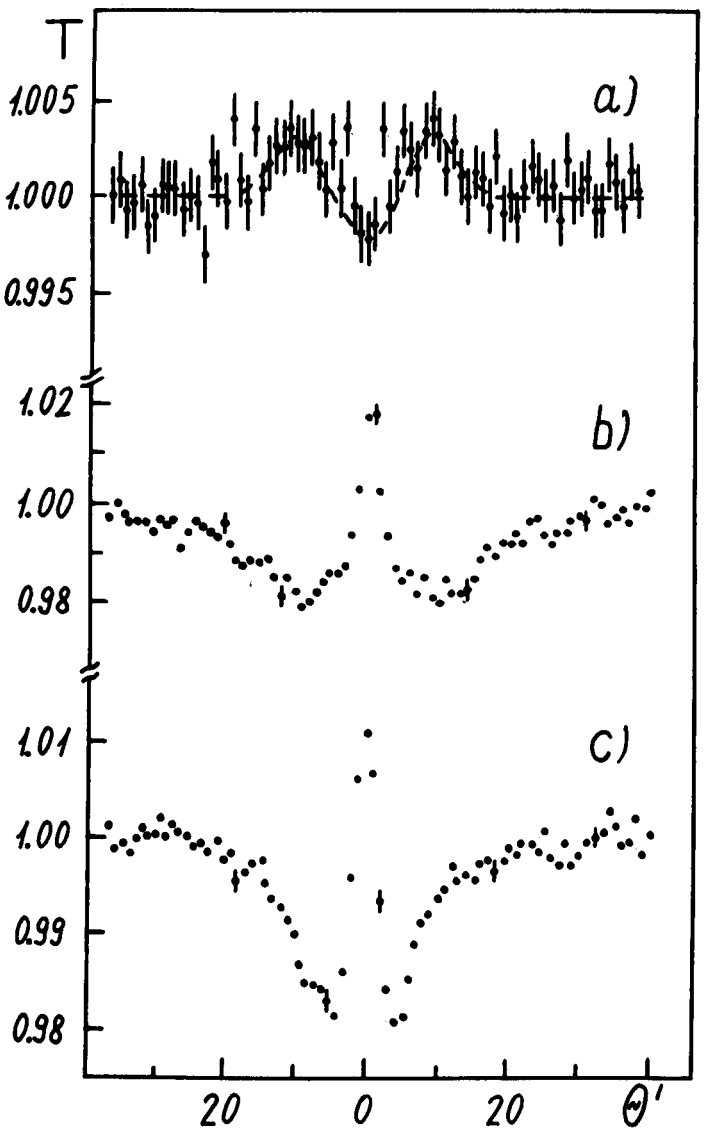

Fig.2. The same dependence (see Fig.1) of the transmission coefficient for (a) neutrons in Ge and for γ-rays in (b) Ge and (c) Sb for $E_\gamma > 1.5$ MeV

1. As this should be expected for large incidence angles ($\Theta > 20'$) the transmission coefficient T turned out to be constant and was assumed to be unity. The data in this range of angles can be fitted by a straight line parallel to the horizontal axis with $\chi^2 \approx 1$.

2. The T versus Θ dependence reveals a minimum with the crystal axis aligned along the beam. Its amplitude reduced to the atomic cross section is $\sim 1.2 \cdot 10^{-25}$ cm^2 for Sb and $\sim 3 \cdot 10^{-26}$ cm^2 for Ge. The halfwidth of the minimum for Sb concides with the instrumental characteristic of $\sim 3'$, where for Ge it is $\sim 10'$.

3. For $\Theta \sim 10'$ one observes on Ge maxima corresponding to $\sigma \approx 2 \cdot 10^{-26}$ cm^2 with a FWHM $\sim 10'$ implying an enhanced transmission of the crystal compared with an arbitrary orientation. In principle, the same maxima, although with a poorer statistical accuracy,

can be seen to exist also for a Sb crystal, an evaluation of their amplitude yielding $\sigma \approx 4 \cdot 10^{-26}$ cm^2. The ratio of these quentities for Ge and Sb is about the same as that of the total cross sections of interaction for $E_n \sim 3$ MeV.

The angular dependence of the γ-ray transmission coefficients for Sb and Ge crystals has also been studied. The measurements were carried out on the same samples and in the same way as those with neutrons. The results of measurements are presented in Fig.2 which also shows for comparison the T versus Θ relation for fast neutrons in Ge obtained in the same angular range. The results obtained with γ-rays can be summarized as follows:

1. For $\Theta > 30'$, T does not depend on the angle. Such measurements, although not presented in this letter, were carried out repeatedly over a broad angular range. We assumed here $T = 1$.

2. With the crystal axis aligned along the beam we observed, in contrast to the case with neutrons, a narrow peak with a FWHM$\sim 3'$ corresponding to the angular resolution of the setup. For Ge and Sb the amplitudes of the maxima taken with respect to the $T = 1$ level and reduced to the atomic cross sections correspond to $\sigma \approx 10^{-25}$ cm^2 and $\sigma \approx 2 \cdot 10^{-25}$ cm^2, accordingly, their ratio being approximately equal to that of the total cross sections of interaction.

3. The minima in the angular dependence of T present on both sides of $\Theta = 0$ can be attributed to the removal from the direct continuum γ-ray beam of the photons whose wavelength at the given angle meets the Bragg condition for the crystal planes passing through the axis in question. Indeed, as the γ-ray discrimination level was raised to 6 MeV the width of the minimum decreased accordingly.

4. Just as in the case with neutrons, it is with the orientation of the crystal axis relative to the beam that the $\Theta = 0$ peak in the angular dependence of the transmission coefficient is related.

5) The peak amplitude is practically independent of the γ-ray discrimination level in the range (1.5–6) MeV.

So in our experiments a complex orientational dependence of the transmission coefficients for fast neutrons and γ-rays incident upon crystals at small angles ($\pm 20'$) in relation to the crystallographic axis has been first revealed. For fast neutrons one observes at $\Theta = 0$ a minimum corresponding to additional scattering, and at $\Theta \sim 10'$, maxima suggesting a slight enhancement of transmission compared with the case of an arbitrerily oriented crystal. For γ-rays the transmission becomes enhanced as the single crystal axis is aligned with the beam direction.

While no calculations which would account for the totality of the experimental data obtained have been made one can suggest the following considerations for their interpretation.

The presence of the minimum in the transmission coefficient for a crystal aligned along the beam follows from a theoretical analysis [1,2]. The experimental data agree satesfactarily with these calculations.

One can, on the other hand, propose the following qualitative reasoning. In the interaction with a crystal lattice aligned along the beam the density of the incident wave along the crystallographic axes can differ from that between them which could result in suppression of the scattering and absorption processes. The latter may lead to an enhancement of transmission in an interval of incidence angles. In particular, the present experimental data permit a reasonable evalution [3] of the total internal reflection of γ-rays close to the crystallographic axes where the electron density exceeds by far its mean value.

The above gives grounds to suggest the existence of channeling of fast neutrons and γ-rays similar to the orientational phenomena observed with charged particles.

We can consider that the phenomenon of fast neutron and γ-ray channeling has been experimentally observed in passing through oriented germanium and antimony crystals.

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