INCREASE IN THE YIELD OF NUCLEAR REACTION PRODUCTS WHEN A SINGLE CRYSTAL TARGET IS USED

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1. It was noted in [1] that when a single-crystal target is used the yield of the nuclear-reaction products induced by charged particles is greatly decreased if the incident beam is directed along one of the principal crystal axes, i.e., if the conditions of the so-called channeling of the beam are satisfied. This phenomenon can be observed experimentally for the case of the reaction (p, γ) on Al and Si single crystals. It is shown below that conditions exist under which the channeling effect leads to the opposite phenomenon - an increase in the reaction-product yield.

When the channeling conditions are satisfied, the quasiperiodic character of the transverse particle motion in the channel causes the distribution of the average particle density over the cross section of the channel to be highly uneven. The particle density reaches a maximum at the center of the channel and decreases towards the periphery, giving rise to a unique focusing of the particles in the channels. It is obvious that if the nuclei involved in the investigated reaction are located near the channel axis, then conditions will be produced for "impact" bombardment, leading to an increase in the reaction-product yield. An essential factor in this increase is also the increase in the average range of the bombarding particles as they move in the channel [2]. To separate the rise in the yield in pure form, it is advantageous to place on the channel axis nuclei that are different from those of the main lattice. In principle, the system of atoms introduced into the channel will disturb the motion of the particles in the channels, but under certain conditions the disturbance can be negligible. For an estimate of the degree to which these conditions are satisfied, we can use the quantity $\alpha = (Z_2/Z_1)(\ell_1/\ell_2)$, where Z_1 and Z_2 are the charges of the nuclei of the main lattice and of the "impurity" and ℓ_1 and ℓ_2 are the distances between neighboring nuclei in the corresponding chains. It is easy to show that the disturbance can be disregarded when $\alpha \ll 1$. The situation described above can arise both when the crystals contain interstitial impurity atoms and in the case of complex crystals containing nuclei with noticeably differing values of Z. All the foregoing pertains, of course, not only to channels located along the principal axes of the crystal, but also to channels produced by neighboring lattice planes [1].

2. We investigated the reaction $H^2(d, p)H^3$ with a single crystal of Nb, impregnated with deuterium to an atom-number concentration of 1%. In this case the condition $\alpha \ll 1$ was certainly satisfied. It is known from the literature (see [3]) that the hydrogen atoms can be disposed in the Nb cell (body-centered cubic lattice) in either the octahedral or tetrahedral interstices. Figure 1 shows the projections of the chains of niobium atoms and the possible locations of the hydrogen atoms on the {111} plane. It is seen from the figure that the hydrogen atoms lie in the central regions of the channels directed along the {111} axis.

It was this axis which we aligned in the direction of the deuteron beam. The measurements were made with the cascade accelerator of the Moscow University Nuclear Physics Institute, at a deuteron energy of 440 keV. The angle scatter of the beam particles did not exceed 0.2°.

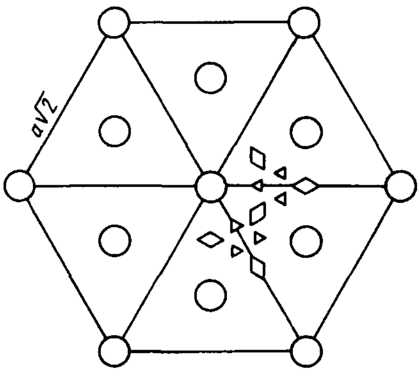

Fig. 1. Projection of crystal lattice of niobium with deuteron impurity on the {111} axis. o - projections of chains of niobium atoms, ◇ - projections of chains of centers of octahedral interstices, △ - projections of chains of centers of tetrahedral interstices.

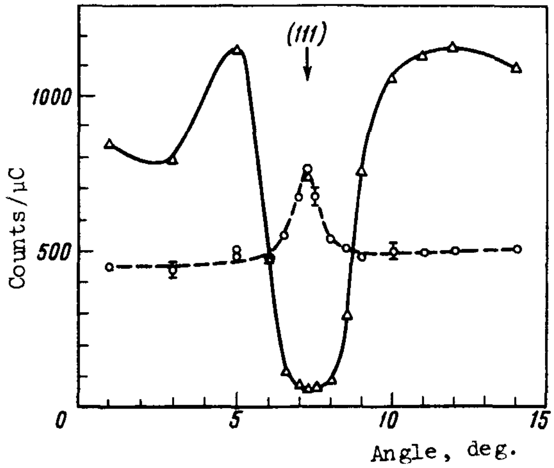

Fig. 2. Dependence of the yield of (d, p) reaction (- o -) and of elastic scattering (- △ -) on the angular position of the target relative to the beam.

The initial orientation of the sample was with the aid of the shadows produced in the angular distributions of the deuterons elastically scattered by the single-crystal target. To make the orientation more precise, we measured the dependence of the yield of elastically scattered deuterons on the angle between the {111} axis and the beam direction. The angle was varied by rotating the target. The minimum yield corresponded to alignment of the crystal axis with the beam axis. The protons from the reaction $H^2(d, p)H^3$ were registered with a semiconductor counter.

To prevent the change in shadow position, resulting from the target rotation, from introducing a noticeable error in the determination of the reaction-products yield, the aperture of the counter was chosen sufficiently large (0.390 sr). The large counter dimensions made it also possible to reduce the total irradiation dose, an important factor if the radiation damage to the lattice is to be minimized. Figure 2 shows the dependence of the yield of protons from the reaction $H^2(d, p)H^3$ and of the elastically scattered deuterons on the angle between the {111} axis of the crystal and the beam axis. It is seen from Fig. 2 that when the channeling conditions are satisfied, the reaction-products yield increases. The relatively small width of the proton peak may be due to the fact that the increase in the reaction yield is connected essentially with the deuterons moving near the channel axis; it is obvious that the entrance angles corresponding to these deuterons are much smaller than the critical channeling angle.

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COMPLEX OSCILLATION OF THE PHOTOMAGNETIC EFFECT IN n-InSb IN A STRONG MAGNETIC FIELD

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The quantization of the electron spectrum of a semiconductor in a strong magnetic field ($uH/c \gg 1$) leads, under certain conditions, to an oscillatory field dependence of all the physical quantities characterizing the phenomena in which the carriers play a noticeable role. Kikoin and Lazarev [1] have shown that these quantities include also the Kikoin-Noskov photomagnetic-effect emf (PME).

We know at present of two types of oscillations of the kinetic coefficients, which are periodic in the reciprocal field. The Shubnikov - de Haas (SH) oscillations are observed only in the case of strong degeneracy ($\zeta \gg kT$) and low temperatures ($kT \ll \hbar\Omega$). The occurrence of these oscillations is connected with a displacement of the Landau levels relative to the Fermi level ζ when the magnetic field is varied. The condition for the crossing of these levels

$$\zeta(H) = \hbar\Omega(N + \frac{1}{2}) \pm \frac{1}{2}|g|\mu_B H \quad (1)$$

($\Omega = eH/m^*c$, g - spectroscopic splitting factor, μ_B - Bohr magneton) determines the periodicity of the SH oscillations. In the case of a spherical zone, without account of the spin splitting, the oscillation period is determined only by the concentration:

$$\Delta(1/H) = 3{,}18 \cdot 10^6 \cdot n^{-2/3}. \quad (2)$$

Variation of n, which can be readily realized in semiconductors, makes it possible to shift the SH oscillation pattern along the scale of the magnetic field [2].

The second type of oscillations, predicted by Gurevich and Firsov (GF), is the consequence of the resonant character of inelastic scattering of electrons by optical crystal vibrations in a strong magnetic field [3]. In this case the oscillation period does not depend on n and is determined by the electron effective mass m* and by the frequency ω_0 of the longitudinal optical phonons: