PROTON SCATTERING BY A TUNGSTEN SINGLE CRYSTAL

V. S. KULIKAUSKAS, M. M. MALOV and A. F. TULINOV

Institute of Nuclear Physics, Moscow State University

Submitted March 13, 1967

Zh. Eksp. Teor. Fiz. 53, 487–489 (August, 1967)

Scattering of 500-keV protons by tungsten single crystals is investigated experimentally. The scattering intensity is drastically reduced in the case of simultaneous channeling along the [100] direction and blocking in the [111] direction. The possibility of using this effect to determine the degree of lattice perfection is discussed.

It has been shown in several investigations that the intensity of elastic particle scattering by a single crystal is sharply reduced as a result of channeling (i.e., the incident particle is aligned with a principal axis or plane).[1,2] It has also been found[3-5] that in the case of beam incidence on a monocrystalline target at an arbitrary angle, the angular distribution of the scattered particles will exhibit dips (regions of sharply attenuated particle intensity) in the directions of the crystal axes and planes.

When the conditions for channeling and blocking (indicated by dips) are fulfilled simultaneously we should obviously observe an even more drastic reduction of the scattered product (or reaction) yield as compared with the case of an amorphous target. In the present work this effect is investigated in the case of elastic proton scattering by a tungsten single crystal.

Our measurements were obtained at the cascade generator of the Institute of Nuclear Physics at Moscow State University, using a 500-keV proton beam (of 0.3 mm diameter and $<0.2^\circ$ spread) aligned with the [100] crystal axis. A semiconductor counter was positioned in the [111] direction (at 126°). The technique used to orient the crystal is extremely important in this type of experiment; it is expedient to orient the crystal during the very measuring process by using the blocking and channeling effects. A technique was developed for controlled rotation of the crystal in three independent planes and for angular displacement of the counter in the horizontal and vertical planes. All these operations were performed without disturbing the vacuum.

For the orientation procedure a fluorescent screen was set up at the end of the collimator, with a center hole for beam passage. The proton scattering patterns on the screen were observed visually.[6] By rotating the crystal the [100] axis was brought into coincidence with the beam direction; the exact moment when this occurred was marked by a sharp decrease in screen illumination; this resulted from channeling of the incident beam. The [100] axis was aligned more precisely with the beam by means of the scattered-proton minimum registered with a semiconductor counter stationed in the direction of one of the strongest dips. When the channeling conditions are satisfied the total intensity of particles scattered by the crystal is drastically reduced; it thus becomes somewhat difficult to position the counter exactly at the center of the dip. In practice it was best, after satisfying the conditions for channeling, to rotate the crystal through a fixed angle in the horizontal plane, and to set the counter to the minimum intensity at the center of the [111] dip; the crystal was then rotated back to its original position and the counter was displaced by exactly the same angle.

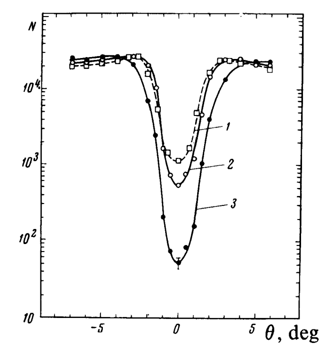

FIG. 1. Yield W of protons scattered by a single crystal *versus* rotational angle of the target. 1 – blocking; 2 – channeling; 3 – simultaneous channeling and blocking.

The combined blocking and channeling effects can easily be observed by rotating the crystal gradually in the horizontal plane. Channeling and blocking are thus manifested simultaneously. At relatively large rotational angles a crystalline target scatters particles exactly like an amorphous target. Curve 3 in Fig. 1 shows how the number of particles registered by the counter depends on the crystal's angle of rotation. Curve 1 represents the case where the counter viewed the center of the dip but the channeling conditions were not maintained. Curve 2, on the other hand, represents channeling of the incident beam with the counter outside of the dip. Curve 3 shows the great depth of the minimum.

Our minimum experimental intensity was under 0.2% of the intensity far from the minimum; however, this ratio cannot be considered as a limiting value. The effect is especially clear in Fig. 2, which shows the energy spectra of elastically scattered protons registered by a 100-channel pulse-height analyzer under the conditions corresponding to curve 3 of Fig. 1. Spectrum 1 of Fig. 2 corresponds to the minimum of that curve; spectrum 2 was obtained with a 5° rotation of the crystal. It is easy to select segments of spectrum 1 where the minimum is considerably deeper than that of curve 3 in Fig. 1 (which was plotted with an integral discrimin-

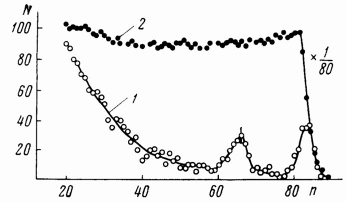

FIG. 2. Energy spectrum of scattered protons. 1 – simultaneous channeling and blocking; 2 – absence of both effects. Ordinates represent the number N of pulses in a channel; abscissas represent the number n.

ator threshold corresponding to the 70th channel). Spectrum 1 exhibits two peaks; the peak in the region of the 83rd channel obviously represents proton scattering on a thin surface layer of a crystal with imperfect structure. In a special experiment this peak was greatly enhanced by depositing a thin gold layer on the surface of a tungsten crystal. The peak in the region of the 65th channel appears to reflect decomposition products of oil vapor from the vacuum system that had been deposited on the surface layer of the target.

The foregoing results show that in the case of simultaneous channeling and blocking the ordered portion of the scattering system makes only a very highly attenuated contribution to the intensity of scattered particles. All forms of disorder (structural imperfections, amorphous layers on the surface etc.) are manifested extremely distinctly. The temperature dependence of the given phenomena is of great interest and is now being measured.

It should be noted that the form of spectrum 1 in Fig. 2 does not remain unaltered under prolonged irradiation of the crystal. As radiation-induced defects accumulate, the mean level of the curve rises nonmonotonically. Figure 3 shows the dependence of the scattered-particle intensity on irradiation dosage for

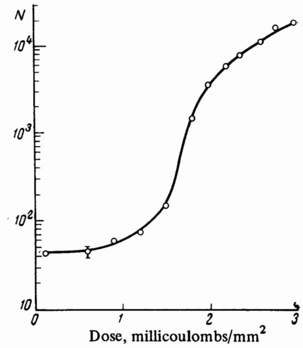

FIG. 3. Counts vs. irradiation dose

integral discriminator threshold corresponding to the 70th channel. It is seen that defects accumulate slowly at first, but that after a critical dosage level is reached the lattice is damaged rapidly.

[1] J. Lindhard, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 34, No. 14 (1965).

[2] E. Bøgh and E. Uggerhøj, Nucl. Instr. and Meth. 38, 216 (1965).

[3] A. F. Tulinov, Dokl. Akad. Nauk SSSR 162, 546 (1965) [Sov. Phys.-Dokl. 10, 463 (1965)].

[4] D. S. Gemmell and R. E. Holland, Phys. Rev. Letters 14, 945 (1965).

[5] A. F. Tulinov, V. S. Kulikauskas, and M. M. Malov, Phys. Letters 18, 304 (1965).

[6] A. F. Tulinov, B. G. Akhmetova, A. A. Puzanov, and A. A. Bednyakov, ZhETF Pis. Red. 2, 48 (1965) [JETP Lett. 2, 30 (1965)].

Translated by I. Emin
54