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Abstract

Full Text

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ANISOTROPY OF THE SPATIAL DISTRIBUTION OF IONS SCATTERED BY A SINGLE CRYSTAL

(Presented by Academician L. A. Artsimovich, 3 VI 1969)

To elucidate the mechanism of scattering of medium-energy ions by crystals, it is necessary to know the spatial and energy distributions of the scattered ions. However, because of experimental difficulties, ion scattering has so far been studied only in a plane (usually in the plane of incidence of the primary ion beam (1)). In order to carry out spatial measurements, a special apparatus was designed and built, the principal diagram of which is shown in Fig. 1. The energy resolution of the apparatus is about 0.5%. The apparatus makes it possible to study the regularities of ion scattering over a wide range of glancing angles α, azimuthal angles of target rotation β, polar θ and azimuthal φ scattering angles. The scheme of notation for these angles is shown in Fig. 1.

Fig. 1. Diagram of the apparatus and diagram of the notation for angles. 1 — entrance flange; 2 —pump; 3, 9 —vacuum chambers; 4, 8 —bellows; 5 —analyzer chamber; 6 —analyzer plates; 7 —exit slit; 10 —manometric lamp; 11-14 —rotary devices; 15 —analyzer entrance diaphragm. B —rectifier; V —voltmeter; EMU — electrometric amplifier; Φ —Faraday cylinder; α —glancing angle; β —azimuthal angle of target rotation; δ —exit angle of the scattered ions; θ —polar scattering angle; φ —azimuthal scattering angle; ψ —total scattering angle; γ —projection of the angle φ onto the plane of the target

The target was the (100) face of a copper crystal, which was irradiated with a beam of argon ions with an energy of 30 keV. In the course of the experiment, the energy distributions of the scattered ions were measured for various combinations of the angles α, β, θ, and φ. The results obtained were then grouped into

Fig. 2

Figure 2: Fig. 2

series–in order to trace the dependence of the distributions on any one angle with the remaining angles fixed. To speed up the recording of the distributions, in some cases an oscillographic method was used (^{2}).

It was found that both the shapes of the energy distributions of the scattered ions and the intensities of the main peaks of these distributions (hereafter, for brevity, we shall call them simply the intensity of the scattered ions) depend not only on the total scattering angle ψ, but also on the polar and azimuthal scattering angles.

Moreover, it turned out that both of these characteristics of the scattered ions are mirror-symmetric with respect to β and φ (i.e., for example, the energy distributions corresponding to the angles $+\beta$ and $-\varphi$, and $-\beta$ and $+\varphi$, coincide; see Fig. 2B).

However, the most interesting result was the discovery of a sharp anisotropy in the spatial distribution of the scattered ions. It was established that in cases where the plane of incidence of the ion beam is not parallel to any close-packed atomic row of the crystal, the spatial distributions of the scattered ions are broad–Fig. 2A and B, $\beta = +12$-16°, $\theta = 25$-40°. However, when the plane of incidence of the primary-ion beam is parallel to the most close-packed atomic rows $\langle 110 \rangle$ of the target, even a small angular displacement of the analyzer out of the plane of incidence of the primary beam leads to a considerable decrease in the intensity of the scattered ions. Thus, a focusing of the scattered ions occurs, as it were, in the plane parallel to the most close-packed atomic rows of the crystal.

Fig. 2. **A**–dependences of the intensity I of the scattered ions on the azimuthal scattering angle φ for the polar scattering angle $\theta = 27^\circ$ and the glancing angle $\alpha = 13^\circ$.
1–$\beta = -12^\circ$, 2–$\beta = 0^\circ$, 3–$\beta = 12^\circ$.

B–energy distributions of scattered ions for various angles β and φ (intensity is plotted on the ordinate axis, energy on the abscissa axis).
I–$\beta = -12^\circ$, $\psi = 31^\circ$, $\theta = 31^\circ$, $\alpha = 13^\circ$, $\varphi = 0^\circ$;
II–$\beta = -12^\circ$, $\theta = 27^\circ$, $\alpha = 13^\circ$ (a—$\varphi = -15^\circ$, b—$\varphi = -7^\circ$, c—$\varphi = 0^\circ$, g—$\varphi = +7^\circ$, d—$\varphi = +15^\circ$);
III–$\beta = 0^\circ$ (θ, α, and φ the same);
IV–$\beta = +12^\circ$ (θ, α, and φ the same);
V–$\beta = 12^\circ$, $\psi = 31^\circ$, $\theta = 31^\circ$, $\alpha = 13^\circ$, $\varphi = 0^\circ$.

C–dependences of the intensity of scattered ions on the azimuthal scattering angle φ:
1–$\beta = 16^\circ$, 2–$\beta = 0^\circ$, 3–$\beta = +16^\circ$.

Fig. 3

Figure 3: Fig. 3

It is interesting to note that at sufficiently large polar scattering angles (for example 30-40°, see Fig. 2C) the intensity of the scattered ions has a weak dip when the analyzer is located exactly in the plane of incidence of the primary beam, parallel to the most close-packed atom-

atomic rows (i.e., $\beta = 0^\circ$). As the polar scattering angle decreases, the distributions narrow and the minimum disappears. When the emergence angles of the scattered ions become small, the minimum appears again; however, in this case it is broad—see Fig. 2B, $\theta = 17.5^\circ$, $\delta = 4.5^\circ$.

Thus, it turned out that planes parallel to the most closely packed atomic rows of the crystal are, with respect to the regularities of ion scattering, physically distinguished.

Fig. 3. **A** –energy distributions of scattered ions for $\theta = 32.5^\circ$, $\alpha = 15^\circ$ for $\beta = -16^\circ$ (1), -8° (2), -6° (3), -4° (4), -2° (5), 0° (6), 2° (7), 4° (8), 6° (9), 8° (10), 16° (11). **B** –dependences of the intensity I and of the relative energy losses $\Delta E/E_0 = (E_0 - E)/E_0$ of the scattered ions on the azimuthal angle of target rotation β for various α (E_0 is the energy of the primary beam, E is the energy corresponding to the maximum of the energy distribution of the scattered ions).

To determine the angular range over which the closely packed atomic rows influence the regularities of ion scattering, measurements were made of the dependences of the characteristics of the scattered ions on the azimuthal angle of target rotation β. In this case the analyzer was always located in the plane of incidence of the primary ion beam ($\varphi = 0^\circ$), and the measurements were carried out at specified angles θ and α. Typical results are shown in Fig. 3, where the energy distributions of the scattered ions for different azimuthal angles of target rotation and the dependences on β of the intensities and relative energy losses of the scattered ions are presented. It is seen that if neither the glancing angle nor the emergence angle of the ions is small, then at $\beta = 0^\circ$ the intensity of the scattered ions is maximal and the energy losses are minimal (see Fig. 3, $\alpha = 10$-15°). If either the glancing angle, or the emergence angle, or both of these angles are small, then at $\beta = 0^\circ$ the intensity of the scattered ions has a minimum, and the energy losses a maximum. Transitional cases are also clearly traced (see Fig. 3).

Comparing the dependences of the scattering characteristics on the angles of rotation of the target and of the analyzer, one may conclude that, in the case we studied of scattering of 30-keV argon ions by a copper crystal, the region of influence of the closely packed ⟨110⟩ rows of atoms is a cone with an apex angle of about 10°.

It is interesting to note that some of the observed effects—such as the blocking effects at the entrance and exit of the scattered ions and the character of the behavior of the energy losses—admit a qualitative explanation on the basis of theoretical models of scattering by isolated rows of atoms ([3-5]). However, the existence of a sharp anisotropy of the spatial distribution of scattered ions apparently indicates that, in scattering···

In the scattering of ions by crystals, the correlation of collisions of ions with different atomic chains plays an important role.

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