# STRUCTURE OF THE ENERGY SPECTRUM OF IONS SCATTERED BY A SINGLE CRYSTAL

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## Abstract

## Full Text

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**PHYSICS**

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# STRUCTURE OF THE ENERGY SPECTRUM OF IONS SCATTERED BY A SINGLE CRYSTAL

*(Presented by Academician L. A. Artsimovich on 15 May 1965)*

In ([1]) it was shown that, starting from a simple model of elastic pairwise single and multiple collisions and a screened Coulomb potential, one can explain the main features of the reflection of ions (atoms) from the surface of a solid polycrystalline body. It was also indicated there that, for single crystals, one should expect anisotropy of the angular distribution and a structure in the energy distribution of the scattered particles.

In ([2]) the structure of the energy spectrum of ions scattered by a single crystal was calculated, and it was shown that, against the general background due to multiple scattering, a series of secondary peaks should stand out, along with the main one. These peaks, located mainly in the high-energy part of the spectrum, correspond to scattering as a result of double collisions with lattice atoms.

**Fig. 1.** Crystal diagram. Atoms on the side faces are not indicated

The present communication gives the results of a study undertaken in order to detect the indicated structure of the high-energy part of the spectrum of scattered ions. The (100) and (114) faces of a copper crystal were bombarded with argon ions of energy 30 keV. The incident and scattered beams lay in the (110) plane (Fig. 1). As follows from ([2]), the peaks farthest from the main one should be observed at large scattering angles. Therefore the experimental apparatus ([3]) was improved so that measurements could be made at large scattering angles. The scattering angle was chosen to be $\varphi = 50^\circ$. The grazing angle of the ions $\theta$ was varied from 10 to 30°. The measurement results are presented by the solid curves in Fig. 2; only the high-energy part of the spectrum, which is of interest to us, is shown. The part of the spectrum located to the left of the main maximum and containing peaks of sputtered and multiply charged

Fig. 2

Figure 2: Fig. 2

reflected ions is analogous to that described in ([4]). As can be seen from Fig. 2, on all curves a feature (a hump) is observed lying to the right of the main peak. Since the orientation of the faces, the ion energy, and the grazing and scattering angles in the present work differed from those assumed in ([2]), a calculation was carried out to determine whether the observed feature corresponds to the effect predicted in ([2]). The calculation was performed by the same method as in ([1,2]), with the additional inclusion of inelastic energy losses in the collision of an ion with an ato-

faces of the crystal. They were estimated by the formula proposed by O. B. Firsov [5]:

$$Q = \frac{(Z_1 + Z_2)^{5/3}\, 4.3 \cdot 10^{-8} u_0}{\left[1 + 3.1\,(Z_1 + Z_2)^{1/3} \cdot 10^7 R_0\right]^5}.$$

where $u_0$ is the ion velocity; $R_0$ is the distance of closest approach corresponding to scattering through the given angle; $Z_1$ and $Z_2$ are the atomic numbers of the colliding particles.

**Fig. 2.** *A* –face (100), *B* –face (114). Scattering angle $\varphi = 50^\circ$. Glancing angles $\theta$: *a* $-10^\circ$, $-15^\circ$, $-20^\circ$, $-25^\circ$, $-30^\circ$.

In accordance with (6), it was also assumed that the energy transferred inelastically is distributed between the ion and the lattice atom in proportion to the number of electrons in their shells: $Q_1/Q_2 = Z_1/Z_2$. Allowance for inelastic losses leads to a shift of the main peak to the left by the amount $Q_1(\varphi)$, and of the remaining peaks by the amount $Q_1(\varphi_1) + Q_1(\varphi_2)$, where $\varphi_1$ and $\varphi_2$ are the scattering angles in the first and second collisions. The results of the calculation are shown in Fig. 2 in the form of separate peaks. The principal maximum (000) corresponds to scattering through the angle $\varphi$ as a result of a single collision with an atom located at the origin of coordinates. The indices at the remaining peaks indicate the crystallographic direction of the atom at which the second scattering occurs, after the first scattering at the atom (000) (see Fig. 1). As is seen from Fig. 2, the largest of the secondary maxima corresponds to the first scattering in the direction (110) and to the second scattering at the atom (1/2, 1/2, 0). The main part of the feature can be identified with this maximum,

observed on the experimental curves, although at certain glancing angles this feature is caused by scattering in other directions (see, for example, Fig. 2B, $\theta = 25^\circ$, $\theta = 30^\circ$). In contrast to the feature found in ([7]), the hump found in the present work cannot be explained by an isotope effect. The isotope peak in our case is only 340 eV away from the main one. It is shown in Fig. 2 by a dotted line.

The resolving power of the analyzer has not yet made it possible to reveal a finer structure of the spectrum. This requires further improvement of the apparatus, which is expected to be carried out in the near future.

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*Note: Figure translations are in progress. See original paper for figures.*