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Figure 2

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Abstract

Full Text

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PHYSICS

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ON MULTIPLE COLLISIONS IN THE SCATTERING OF IONS BY CRYSTALS

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It is known that the energy spectra of ions scattered by the surfaces of solids contain a number of peaks which correspond to ions scattered both without a change of charge and after undergoing stripping during scattering. Usually (see, for example, ([1–3])) the positions of these maxima

Fig. 1. Energy spectra in the scattering of argon ions for scattering angles θ: 1–25°, 2–30°, 3–35°, 4–37.5°, 5–40°, 6–45°, 7–45°

correspond to the energy of ions that have undergone single scattering on target atoms.

It has recently been established that, when ions are scattered by crystals, the spectra also contain peaks caused by multiple scatter-

Fig. 2. Energy spectra for the scattering of neon ions. **1** —dependence of the intensity of the maximum peak on the scattering angle; **2** —$\theta = 25^{\circ}$, **3** —35°, **4** —45°, **5** —50°.

Fig. 3. Energy spectra in the scattering of krypton ions for scattering angles θ: **1** —10°, **2** —15°, **3** —20°, **4** —25°, at a glancing angle $\alpha = 7^{\circ}$; **5** —dependence of the

Figure 3

Figure 3: Figure 3

intensity of the maximum peak on the scattering angle at $\alpha = 7^\circ$. Dashed line –rotation about the [100] axis; solid lines –rotation about the [110] axis. **6** – high-energy portions of the spectra in scattering by the surface of polycrystalline tungsten.

···them [(4)]. It will be shown below that in a number of cases these peaks are very large, and the spectra are determined mainly by ions that have undergone multiple scattering. The target was the (100) face of a nickel crystal. To trace the dependence on the distance between the scattering atoms, the scattering was studied for two rotations of the target: about the [110] axis and about the [100] axis (see Fig. 1). In the first case the distance between neighboring scattering atoms is the minimum possible: $a/\sqrt{2} \sim 2.5$ Å; in the second, $a \sim 3.5$ Å (see, for example, [(5)]).

To trace the dependence on the atomic number of the ion, irradiation was carried out with ions having strongly differing atomic numbers: $^{20}Ne^{+}$ and $^{40}Ar^{+}$ ions of energy 30 keV, and also $^{84}Kr^{+}$ ions of energy 25 keV; the scattering angles were varied from 10 to 50°. Analysis of the scattered ions was performed by means of an analyzer with an energy resolution of 1%. The measurement results are shown in Figs. 1–3.

For convenience in comparing the results for different scattering angles and target rotations, when constructing the spectra the intensity of the maximum peak was taken as unity. In the graphs, the solid lines mark the energy positions of the "single-scattering" component, and the dashed line those of the "double-scattering" component (see the scattering schemes in Fig. 1). The energy of the scattered particles was calculated according to the laws of elastic collisions of free particles.

Comparison of the spectra at a fixed scattering angle for two different rotations of the target shows that a decrease in the distance between scattering atoms leads to an increase in the relative intensity of double scattering (see, for example, Fig. 1).

An increase in the relative intensity of double scattering is also caused by a decrease in the scattering angle at a fixed glancing angle. For example, for $^{40}A^{+}$ ions in the case of rotation about the [110] axis, when the scattering angle is decreased to 30–25°, the intensity of the "double" component becomes greater than the intensity of the "single" component; and for $^{84}Kr^{+}$ ions (Fig. 3), for the same rotation, at scattering angles of 20–10° the spectra are determined mainly by ions that have undergone double scattering.*

It should be noted that, for ions that have undergone charge stripping during scattering, the intensity of double scattering is lower than for ions scattered without a change of charge (see, for example, Fig. 1). An analogous decrease in the effect of multiple collisions on the spectrum with increasing ion charge was observed by Datz and Snoek ([2]) in studying scattering by polycrystalline surfaces.

Fig. 4. High-energy portions of the spectra in scattering of neon, argon, and krypton ions by a copper crystal for $\theta = 25^{\circ}$. Rotation about the [110] axis. Upper right—the mass line of krypton ions in the absence of the target

Figure 4: Fig. 4. High-energy portions of the spectra in scattering of neon, argon, and krypton ions by a copper crystal for $\theta = 25^{\circ}$. Rotation about the [110] axis. Upper right—the mass line of krypton ions in the absence of the target

Comparison of the spectra for scattering of neon and argon ions shows that, for neon, the relative intensity of double scattering is lower than for argon; moreover, the components either are poorly resolved or are not resolved at all. This is partly connected with the fact that the energy separations between the components are considerably smaller for neon than for argon. A deterioration of the resolution associated with a decrease in the energy separation between the components is also observed when the scattering angle is decreased for scattering of argon ions.

Fig. 4. High-energy portions of the spectra in scattering of neon, argon, and krypton ions by a copper crystal for $\theta = 25^{\circ}$. Rotation about the [110] axis. Upper right—the mass line of krypton ions in the absence of the target.

One more circumstance, well known in high-resolution spectroscopy ([6]), also contributes to the deterioration of the resolution: the apparent convergence of close components when their contours partially overlap. Indeed, at some scattering angles the maxima of the peaks of the single component lie to the right, and those of the double component to the left, of the calculated values. The resulting increasing overlap of the component contours and the presence of background also lead to distortion of the ratios of the component intensities. This should be kept in mind when comparing experimental data with theoretical calculations.

The influence of the atomic number of the ion on portions of the spectrum, due to multiple—

* Similar regularities are also observed on a copper crystal; see Fig. 4.

···scattering (to the right of the single-scattering maximum) can also be clearly traced on polycrystalline targets. Figure 3 shows the high-energy parts of the spectra for the scattering of $^{20}Ne^{+}$, $^{40}Ar^{+}$ (30 keV), and $^{84}Kr^{+}$ (25 keV) ions by the surface of polycrystalline tungsten. It is seen that in the case of neon the spectrum is comparatively narrow and the part due to multiple scattering is expressed very weakly. In the case of argon this part increases, and for krypton it becomes very significant.

The observed regularities are in good agreement with conclusions based on consideration of the simplest two-atom scattering model, taking the interaction into account by means of the Firsov potential; according to this model the relative probability of double scattering should increase as the atomic numbers of the ion and the atom increase, as the energy and scattering angle of the ion decrease, and also as the distance between the scattering atoms decreases*.

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* This consideration is inapplicable at small glancing and scattering angles because of the shielding of some atoms by others.

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