ON AN EXPERIMENTAL TEST OF THE CHAIN MODEL IN THE SCATTERING OF IONS BY CRYSTALS

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Abstract

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I. N. EVDOKIMOV, E. S. MASHKOVA, V. A. MOLCHANOV

ON AN EXPERIMENTAL TEST OF THE CHAIN MODEL IN THE SCATTERING OF IONS BY CRYSTALS

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The important significance of simple, intuitive, and physically clear models, within the framework of which it has proved possible to carry out a purposeful investigation of the basic regularities of ion scattering, has been realized only recently. The best-known general result obtained in recent years has been the establishment of the fact that even the simplest models of this kind give a fairly good qualitative description of rather complex experimental material accumulated in the study of the scattering of medium-energy ions by solid surfaces.

Thus, the simplest of the models—the one-atom model—under the condition that the interaction of an ion with a target atom is described by a screened Coulomb potential, qualitatively correctly conveys the general character of the angular distributions of scattered ions, the presence in the energy distributions of peaks of ions and recoil atoms, the dependence of the relative intensity of these peaks on the scattering angle, and some other questions (see, for example, ([1])).

The next model in order of complexity—the two-atom model—already gives a qualitatively good description of such a complex phenomenon as the effect of multiple scattering of ions by crystals ([2], [3]). It correctly conveys the dependence of the multiple-scattering effect on the atomic numbers of the ion and the target atom, the distance between target atoms, the ion energy, and the scattering angle.

In ([4]) another, somewhat more complex, model was proposed—the model of scattering by the ridge of a plane chain of atoms. Consideration of the chain model (it was carried out by numerical methods) leads to the following conclusions.

First, at small scattering angles the flux of scattered ions is bounded both on the side of large and of small scattering angles (see also ([5])). Second, although the multiplicity of scattering turns out to be comparatively high, for given angles of incidence and scattering of the ions only two maxima should be observed in the energy distribution of the scattered ions. However, the positions of these

maxima on the energy scale differ from those following from the two-atom scattering model: the maxima are closer together and shifted into the region of higher energies; moreover, they have a finite width, whereas in the two-atom model the maxima are infinitely narrow. Unfortunately, in ([4]) only the positions of the maxima are indicated, but not the form of the energy distribution of the scattered ions.

The results of the calculation presented in ([4]) allow direct comparison with experiment. In doing so, however, several parameters remain uncertain. First, the calculation was carried out for a parallel beam of ions incident on an infinite ideal plane chain, and the energy and angular distributions were obtained for exactly specified scattering angles. In the experiment, both the primary and the scattered ion beams are always characterized by finite magnitudes of spreads in angles and energies. Second, in the calculation it was assumed that

thermal vibrations of the atomic chain are absent. In the experiment this condition cannot be fulfilled. All the other parameters (the type of atoms in the chain, the distances between them, the type and energy of the ions, and the angles of incidence and scattering) in the experiment were taken to be the same as those for which the calculation was carried out ([4]). The experimental procedure was the usual one (see, for example, ([6], [7])): a beam of argon ions with an energy of 30 keV was directed onto the (100) face of a copper crystal, the rotation of which was carried out about the [110] axis (under such rotation the [110] chain lay in the scattering plane). The angles of incidence of the ions were 8, 12, 14, and 16° with the axis of the chain; the scattered ions were studied by means of a 1% electrostatic analyzer.

Fig. 1

Fig. 2

The dependences of the experimentally obtained energy distributions on the ion scattering angle are shown in Figs. 1 and 2. Above them are shown the calculated values of the positions of the high-energy and low-energy peaks according to the two-atom scattering model (dashed curves) and according to the chain model (dash-dotted ovals) from (*).

There, the solid curve shows the dependence of the energy position of the peaks in the experimental distributions on the scattering angle. This curve was constructed in the following way. If, at some scattering angle, two peaks were present in the experimental energy distribution, two points were plotted on the energy–scattering-angle diagram. If, at a given scattering angle, one peak was present, one point was plotted. No points were plotted at all (i.e., it was assumed that scattered particles were absent) if, at the given scattering angle, the intensity of the scattered ions was approximately an order of magnitude less than the maximum intensity corresponding to the given angle of incidence of the ions. All plotted points were connected by a smooth curve.

Let us consider the experimental data obtained. First of all, it is evident that

Fig. 3

Figure 1: Fig. 3

two peaks are observed in the energy distributions only in isolated cases. In most of the distributions obtained there is one peak. The absence of separation of the two peaks apparently cannot be attributed solely to the insufficient resolving power of the apparatus. Indeed, measurements for cases in which other, less densely packed chains [100] and [130] lay in the scattering plane showed a much more distinct separation of the peaks (see, for example, Fig. 1). The poorer separation of the peaks in the case of the [110] chain can to some extent be explained, within the chain model, by the convergence of the peaks (see above). Unfortunately, it is not possible to draw any more definite conclusions, since from the work [4] it is not clear what the calculated dip in the intensity of the scattered ions in the interval between the peaks should be, and what the relative intensity of these peaks should be.

Fig. 3. Dependence of the relative energy losses on the scattering angle θ for glancing angles $\alpha = \theta/2$. *a*—$E = 30$ keV; *b*—$E = 15$ keV; *c*—calculation of elastic losses for the cases of single and double scattering

Let us now turn to the question of the limitation of the scattered-ion beam from the side of large and small scattering angles. Consideration of the energy distributions obtained shows that, at glancing angles of 8 and 12°, the predicted limitation of the scattered beam does not occur (Fig. 1). For comparatively large glancing angles, 14 and 16°, a fairly sharp decrease in the scattering intensity is observed (see Fig. 2) from the side of small scattering angles, although at somewhat smaller values of these angles than follows from [4]. At glancing angles, not only the angular distribution of the scattered particles disagrees with the calculation, but also the energy positions of the peaks—the calculation gives overestimated values of the energies of the scattered ions. The latter circumstance may be connected with the difficulties of accurately calculating the magnitude of inelastic losses (see also [5,8]).

The course of the energy losses as the scattering angle decreases can be followed more clearly by constructing curves of the relative energy losses, averaged over the energy distribution, as a function of the scattering angle. The corresponding curve for ions of energy 30 keV is shown in Fig. 3. It is seen that, along with a decrease in the energy loss as the scattering angle decreases, there is a region of angles in which the energy loss increases. Similar measurements carried out at lower ion energies (20, 15, and 10 keV) showed that the increase in the loss begins at larger scattering angles and has a greater absolute

amount the lower the ion energy. As an example, Fig. 3 gives results for ions with an energy of 15 keV. Similar results were also obtained for cases in which less densely packed chains lay in the scattering plane ([100] and [130]), and for a polycrystal. The latter circumstance apparently permits the conclusion that

the effect of increasing loss occurs independently of the collision with the chain.

The experimental data presented above indicate that some important conclusions of work [4] are not confirmed by experiment. One reason for this, in our opinion, is the circumstance that only a small fraction of the flux of primary ions reaches the crests of the atomic chains. Therefore, for a clear observation of the effects of a surface atomic chain, one should probably seek such experimental conditions under which effects not associated with chains would be reduced to a minimum.

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